(2)

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

NEAR-STALL LOSS MEASUREMENTS IN A CD COMPRESSOR CASCADE WITH EXPLORATORY LEADING EDGE FLOW CONTROL

by

Jeffrey H. Armstrong

June 1990

Thesis Advisor: Raymond P. Shreeve

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited
2b DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: Naval Postgraduate School; 6b OFFICE SYMBOL (If applicable): Code AA	7a NAME OF MONITORING ORGANIZATION: Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
NEAR-STALL LOSS MEASUREMENTS IN A CD COMPRESSOR CASCADE WITH EXPLORATORY LEADING EDGE FLOW CONTROL

12 PERSONAL AUTHOR(S)
Armstrong, Jeffrey H.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month Day)	15 PAGE COUNT
Master's Thesis	FROM ______ TO ______	1990, June	166

16 SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Cascade Wind Tunnel Loss Measurement; Controlled Diffusion Blading; Slotted Leading Edge

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Loss measurements were conducted using a five-hole conical pneumatic probe in a subsonic wind tunnel containing a modeled cascade of controlled diffusion (CD) stator blades. Following reference measurements at high incidence one blade was modified (slotted at the leading edge) in an attempt to (passively) reduce the size of the leading edge separation bubble and thereby improve performance. Prior to the surveys, the acquisition and reduction software was modified to provide loss calculations using both mass-averaged and fully-mixed-out conditions for the upstream and downstream flows. Results showed that the mass-averaged method provided the more consistent results, and this was explained. The slotted leading edge blade was found to produce less loss than the reference blade, and it was concluded that the control concept should be explored in more detail.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL: Professor Raymond P. Shreeve	22b TELEPHONE (Include Area Code): (408) 646-2593; 22c OFFICE SYMBOL: Code AA/SF

DD Form 1473, JUN 86 Previous editions are obsolete SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 UNCLASSIFIED

Approved for public release; distribution is unlimited

Near-Stall Loss Measurements in a CD Compressor Cascade with Exploratory Leading Edge Flow Control

by

Jeffrey H. Armstrong
Lieutenant, United States Navy
B.S., United States Naval Academy, 1983

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
June 1990

Author: Jeffrey H. Armstrong

Approved by: Raymond P. Shreeve

Raymond P. Shreeve, Thesis Advisor

Garth V. Hobson, Second Reader

E. Roberts Wood, Chairman
Department of Aeronautics and Astronautics

ABSTRACT

Loss measurements were conducted using a five-hole conical pneumatic probe in a subsonic wind tunnel containing a modeled cascade of controlled diffusion (CD) stator blades. Following reference measurements at high incidence one blade was modified (slotted at the leading edge) in an attempt to (passively) reduce the size of the leading edge separation bubble and thereby improve performance. Prior to the surveys, the acquisition and reduction software was modified to provide loss calculations using both mass-averaged and fully-mixed-out conditions for the upstream and downstream flows. Results showed that the mass-averaged method provided the more consistent results, and this was explained. The slotted leading edge blade was found to produce less loss than the reference blade, and it was concluded that the control concept should be explored in more detail.

A-1

TABLE OF CONTENTS

I.	INTRODUCTION --	1
II.	EXPERIMENTAL APPARATUS ---------------------------	6
	A. CASCADE WIND TUNNEL -------------------------	6
	B. CONTROLLED DIFFUSION BLADING ----------------	6
	C. INSTRUMENTATION -----------------------------	6
	D. DATA ACQUISITION SYSTEM ---------------------	12
III.	TEST PROCEDURES AND PROGRAM OF MEASUREMENTS -----	16
	A. TEST PROCEDURES -----------------------------	16
	B. PROGRAM OF MEASUREMENTS ---------------------	18
	C. DATA REDUCTION AND PRESENTATION -------------	20
IV.	RESULTS AND DISCUSSION --------------------------	27
	A. FLOW FIELD ----------------------------------	27
	B. REFERENCE AND SLOTTED BLADE PERFORMANCE -----	46
	C. EFFECT OF SLOTTED LEADING EDGE ON FLOW STRUCTURE -----------------------------------	48
V.	CONCLUSIONS AND RECOMMENDATIONS -----------------	50
	A. LOSS CALCULATIONS ---------------------------	50
	B. SLOTTED BLADE -------------------------------	51
APPENDIX A:	SLOTTED BLADE DEVELOPMENT ----------------	52
APPENDIX B:	SOFTWARE ---------------------------------	58
APPENDIX C:	REYNOLDS NUMBER CALCULATION --------------	127
APPENDIX D:	CALCULATION OF COMPRESSIBLE MIXED-OUT CONDITIONS --------------------------------	130

APPENDIX E: FULLY-MIXED-OUT FLOW SOFTWARE TESTING ---- 139

APPENDIX F: PROBE ANGLE REFERENCING ------------------ 147

LIST OF REFERENCES ------------------------------------ 151

INITIAL DISTRIBUTION LIST ----------------------------- 153

LIST OF TABLES

1. Blade Geometry, Cascade Geometry and Nominal Test Conditions -- 9

2. Probe Surveys -- 19

3. Data Reduction Formulae -------------------------------- 22

4. Reference and Slotted Blade Survey Results ------------- 47

B1. CALC Program Listing ---------------------------------- 63

B2. SUBCALC Program Listing ------------------------------- 74

B3. LOSS Program Listing ---------------------------------- 76

B4. SUBMIX/LOSS Program Listing --------------------------- 81

B5. Scanivalve and Scanner Channel Assignments ------------ 85

B6. Example Raw Data File Printout ------------------------ 86

B7. Example Scaled Data File Printout --------------------- 88

B8. Reference Blade Reduced Data File Printout-Upstream ---- 90

B9. Reference Blade Reduced Data File Printout-Downstream -- 92

B10. Slotted Blade Reduced Data File Printout-Downstream ---- 96

B11. Blade Coefficient of Pressure Scaled Data File Printout -- 100

B12. Blade Coefficient of Pressure Reduced Data File Printout -- 101

B13. ACQUIRE Program Listing ------------------------------ 108

B14. SUBACQUIRE Program Listing --------------------------- 120

B15. LOSSCALC Program Listing ----------------------------- 122

B16. CPBLADEPLOT Program Listing -------------------------- 123

B17. BETAPOSIT Program Listing ---------------------------- 124

B18. PRESSPLOT Program Listing ------------------------------ 125

B19. VVREFPLOT Program Listing ------------------------------ 126

E1. Comparison of "LOSS" and Analysis Program -------------- 143

E2. Effects of Varied X, Yaw and Area ---------------------- 145

LIST OF FIGURES

1. Linear Cascade Wind Tunnel Test Facility ---------------- 7

2. Cascade Test Section and Instrumentation --------------- 8

3. Controlled Diffusion Blade Pressure Tap Locations ------ 10

4. Slotted Controlled Diffusion Blade Leading Edge -------- 11

5. Five-hole Conical Probe -------------------------------- 13

6. Data Acquisition System -------------------------------- 14

7. Tunnel Inlet Survey: Beta vs. Probe Displacement, Blade-to-Blade --- 28

8. Tunnel Inlet Survey: V1/Vref vs. Probe Displacement, Blade-to-Blade --- 28

9. Tunnel Inlet Survey; Pref-Pt1/Qref vs. Probe Displacement, Blade-to-Blade --------------------- 29

10a. Reference Blade Upstream Survey: Beta vs. Probe Displacement, Blade-to-Blade --------------------- 30

10b. Reference Blade Upstream Survey: V1/Vref vs. Probe Displacement, Blade-to-Blade --------------------- 30

10c. Reference Blade Upstream Survey: Pref-Pt/Qref vs. Probe Displacement, Blade-to-Blade ----------------- 30

11a. Reference Blade Upstream Survey: Beta vs. Probe Displacement, Span-wise -------------------------- 31

11b. Reference Blade Upstream Survey: V1/Vref vs. Probe Displacement, Span-wise -------------------------- 31

11c. Reference Blade Upstream Survey: Pref-Pt1/Qref vs. Probe Displacement, Span-wise -------------------------- 31

12. Surface Pressure Distribution: Cp vs. X/C -------------- 32

13a. Reference Blade Downstream Survey: Beta vs. Probe Displacement, Blade-to-Blade --------------------- 33

13b. Slotted Blade Downstream Survey: Beta vs.
Probe Displacement, Blade-to-Blade ------------------------33

14a. Reference Blade Downstream Survey: Pref-Pt2/Qref vs.
Probe Displacement, Blade-to-Blade -------------------- 34

14b. Slotted Blade Downstream Survey: Pref-Pt2/Qref vs.
Probe Displacement, Blade-to-Blade -------------------- 34

15a. Reference Blade Downstream Survey: V2/Vref vs.
Probe Displacement, Blade-to-Blade -------------------- 35

15b. Slotted Blade Downstream Survey: V2/Vref vs.
Probe Displacement, Blade-to-Blade -------------------- 35

16a. Reference Blade Downstream Survey: Beta vs.
Probe Displacement, Span-wise, Suction Side ------------ 36

16b. Slotted Blade Downstream Survey: Beta vs.
Probe Displacement, Span-wise, Suction side ------------ 36

17a. Reference Blade Downstream Survey: Pref-Pt2/Qref vs.
Probe Displacement, Span-wise, Suction side ------------ 37

17b. Slotted Blade Downstream Survey: Pref-Pt2/Qref vs.
Probe Displacement, Span-wise, Suction side ------------ 37

18a. Reference Blade Downstream Survey: V2/Vref vs.
Probe Displacement, Span-wise, Suction side ------------ 38

18b. Slotted Blade Downstream Survey: V2/Vref vs.
Probe Displacement, Span-wise, Suction side ------------ 38

19a. Reference Blade Downstream Survey: Beta vs.
Probe Displacement, Span-wise, Pressure side ----------- 39

19b. Slotted Blade Downstream Survey: Beta vs.
Probe Displacement, Span-wise, Pressure side ----------- 39

20a. Reference Blade Downstream Survey: Pref-Pt2/Qref vs.
Probe Displacement, Span-wise, Pressure side ----------- 40

20b. Slotted Blade Downstream Survey: Pref-Pt2/Qref vs.
Probe Displacement, Span-wise, Pressure side ----------- 40

21a. Reference Blade Downstream Survey: V2/Vref vs. Probe Displacement, Span-wise, Pressure side ----------- 41

21b. Slotted Blade Downstream Survey: V2/Vref vs. Probe Displacement, Span-wise, Pressure side ----------- 41

22. Loss Coefficient vs. Air Inlet Angle -------------------- 42

23. Pt/Pref for Upstream and Downstream Surveys ------------ 43

24a. Reference Blade Leading Edge Flow Visualization -------- 44

24b. Slotted Blade Leading Edge Flow Visualization ---------- 44

A1. Slotted Blade Leading Edge, Suction Surface View ------- 56

A2. Slotted Blade Leading Edge, Frontal View --------------- 57

B1. Directory and File Listing ---------------------------- 60

B2. Program "Loss" Flow ----------------------------------- 61

B3. Reference Blade Loss Output --------------------------- 82

B4. Slotted Blade Loss Output ----------------------------- 83

D1. Fully Mixed-Out Conditions for a Stationary Cascade ---- 130

E1. Fully Mixed-Out Flow Test Case ------------------------ 139

E2. Test Case Loss Printout -- Zero Yaw Angle ------------- 141

E3. Test Case Loss Printout -- 20 Degree Yaw Angle --------- 142

E4. Analysis Program Listing ------------------------------ 144

F1. Probe Angle Referencing ------------------------------- 147

F2. From North Side of Free-Jet --------------------------- 148

F3. From South Side of Free-Jet --------------------------- 148

LIST OF SYMBOLS

English Letter Symbols

AVDR	Axial Velocity Density Ratio
C_p	Pressure Coefficient
$\bar{C}_p$	Mass averaged coefficient of pressure from instrumented blade
C_{p2}	Static pressure rise coefficient
C_{p3}	Mixed flow static pressure rise coefficient
c	Chord
c_p	Specific heat at constant pressure
h	Span-wise depth of control volume
M	Mach number
n	Number of scans
P	Pressure
Q	Dynamic pressure
S	Blade spacing
T	Temperature
V	Velocity
x	Position of probe in blade-to-blade direction
X	Nondimensional velocity

Greek Letter Symbols

β	Flow angle
γ	Ratio of specific heats

$\bar{\omega}$	Loss coefficient
ρ	Density

Subscripts

1	Upstream survey station
u	Downstream survey station
a	Atmospheric
L	Local
p	Measured in the plenum
ref	Reference value derived from plenum stagnation and atmospheric pressures
s	Static
t	Stagnation or total
mix	Mixed-out condition

Superscripts

^	Ensemble average of values during a survey

I. INTRODUCTION

The current drive for highly maneuverable, short take off and landing (STOL), and short take off, vertical landing (STOVL) aircraft is generating a demand for efficient aircraft engines which are also capable of operating stably at extreme angles of attack and with distorted inlet flow fields. Such operating conditions push the engines towards stall. Hence there is need for accurately predicting the available stall margin for a new engine, and for developing compressor designs which have wide stall margins at high efficiencies.

Developing components and testing assembled engines for performance and stable operating margins, is enormously costly and a lengthy process. Computational fluid dynamics (CFD) potentially provides a means of modeling the engine flow fields and of evaluating the stall margin and efficiency during the design process. Thus the designer has the ability now to select and incorporate compressor blade shapes which allow the engine to achieve the desired characteristics. The CFD codes used for design purposes must first be validated by comparison with cascade wind tunnel data for flow structure and blade element performance. Laser doppler velocimeter (LDV) systems provide information on the flow structure by mapping the velocity field. Pressure probe measurements are required to determine the loss coefficient, which is the key

measure of the blade performance. Accurate loss measurements using a pressure probe in the Naval Postgraduate School's (NPS) cascade wind tunnel facility, including exploratory tests of a blade leading edge modification, were the focus of the present study.

The cascade wind tunnel was configured with the mid section of a controlled diffusion (CD) stator blade designed by Sanger [Ref. 1] at NASA Lewis Research Center. Previous studies with the present CD blading include the work of Koyuncu [Ref. 2], who conducted pressure probe tests at air inlet angles from 24.3 degrees to 47.2 degrees to establish on- and off-design blade losses. Subsequently, Dreon [Ref. 3] measured losses at various positions moving downstream through the wake and concentrated on verifying the accuracy of the loss measurements at the air-inlet angles of 40.3 and 43.4 degrees. The detailed flow structure was mapped by Elazar [Ref. 4], who obtained LDV measurements of the flow through the passage formed by adjacent blades, of the boundary layer development on the blade surfaces and of the early wake development. Hot-wire measurements were obtained by Baydar [Ref. 5] to verify the LDV measurements of Elazar. Classick [Ref. 6] improved the data acquisition and reduction process for pressure probe measurements using new computer hardware, documented a user manual and made demonstration measurements. Classick's and Dreon's work provided the background for the present study. The cascade flow field was found to be

acceptably periodic and showed good span-wise independence in each of the earlier studies.

In the present work, the software and procedures developed by Classick were used to obtain accurate measurements to establish the blade element performance at a high air inlet angle near stall. The measurements were used to examine the possible standardization of cascade blade loss measurements in terms of "fully mixed-out flow" conditions, and as a reference against which to evaluate performance changes caused by leading edge modifications. Cascade losses as evaluated from the "mass-average" of stagnation pressure surveys can vary depending on the locations of the probe survey stations. Calculating the loss using the fully mixed-out conditions from both the upstream and downstream survey stations, in principle provides a loss measurement that is independent of survey station. With respect to modifying the leading edge, at off-design incidence angles, the leading-edge separation bubble on the suction side of the blade generates a significant loss. By introducing counter rotating streamwise vortices at the leading edge of the blade (by creating a series of diagonal slots to generate a pattern of oblique jets) early reattachment will decrease the bubble size and subsequent growth of the suction side boundary layer, thereby generating smaller losses. Measuring accurately the loss of the reference CD blade and a slotted CD blade will establish the blade element performance improvement.

The present study involved further development of the measurement procedures followed by reference and modified blade measurements. First, the measured yaw angle was correctly referenced to the blade row geometry, completing a procedure initiated by Classick [Ref. 6]. Secondly, the fully mixed-out loss computation was incorporated into the data analysis software and the software was validated using an analytically-constructed test case. A Reynolds number subroutine was also added. Finally comprehensive pressure probe measurements at an air inlet angle of 48.5 degrees were obtained for the reference case and with a single slotted CD blade inserted within the cascade of reference blades. Conclusions of the study were that mass-averaged loss coefficients can be evaluated with less uncertainty than fully mixed-out loss coefficients because of the effects of slightly varying cascade inlet conditions, and that the slotted blade leading edge did create significant upper surface flow modification, leading to a measured blade element performance improvement.

The apparatus for the experiment is discussed in Section II of this report. Section III discusses the test conditions, calibration, referencing, survey runs, survey positions, measurement uncertainties and outlines the measurements taken. Section IV presents the results for the flow field, blade performance, and effect of the modified leading edge on the flow structure. The conclusions and recommendations follow in

Section V. Details of the work are contained in the appendices. Appendix A discusses the slotted blade development, from the concept to the final production procedures. The software, in the form of programs, subprograms, data printouts and directory are provided in Appendix B. The Reynolds number subroutine is shown in Appendix C. Appendix D presents the fully mixed-out flow theory and the validation test problem is given in Appendix E. Appendix F addresses the probe angle referencing procedure. It should be noted that Appendix C of Classick [Ref. 6] serves as a users guide to the computer and software.

II. EXPERIMENTAL APPARATUS

A. CASCADE WIND TUNNEL

Figure 1 shows the NPS cascade wind tunnel facility. The test section and instrumentation are shown in Figure 2. A detailed description of the facility, test section and CD blading is contained in Sanger and Shreeve [Ref. 7].

B. CONTROLLED DIFFUSION BLADING

The design procedure for the reference CD blading is described in Reference 1. Table 1 provides the blade coordinates, cascade geometry and nominal conditions for the tests. Figure 3 shows the profile of a blade and shows the location of pressure taps on the instrumented blade (blade 10 from the left in Figure 2), and the partially instrumented blade (blade 11). The slotted blade leading edge is shown in Figure 4. The slotted blade development from the reference CD blade is given in Appendix A. The reference blade and slotted blade surveys were made behind blade 7.

C. INSTRUMENTATION

The five-hole conical probe used and described by Dreon [Ref. 3] and calibrated by Classick [Ref. 6] was used for all pressure probe measurements.

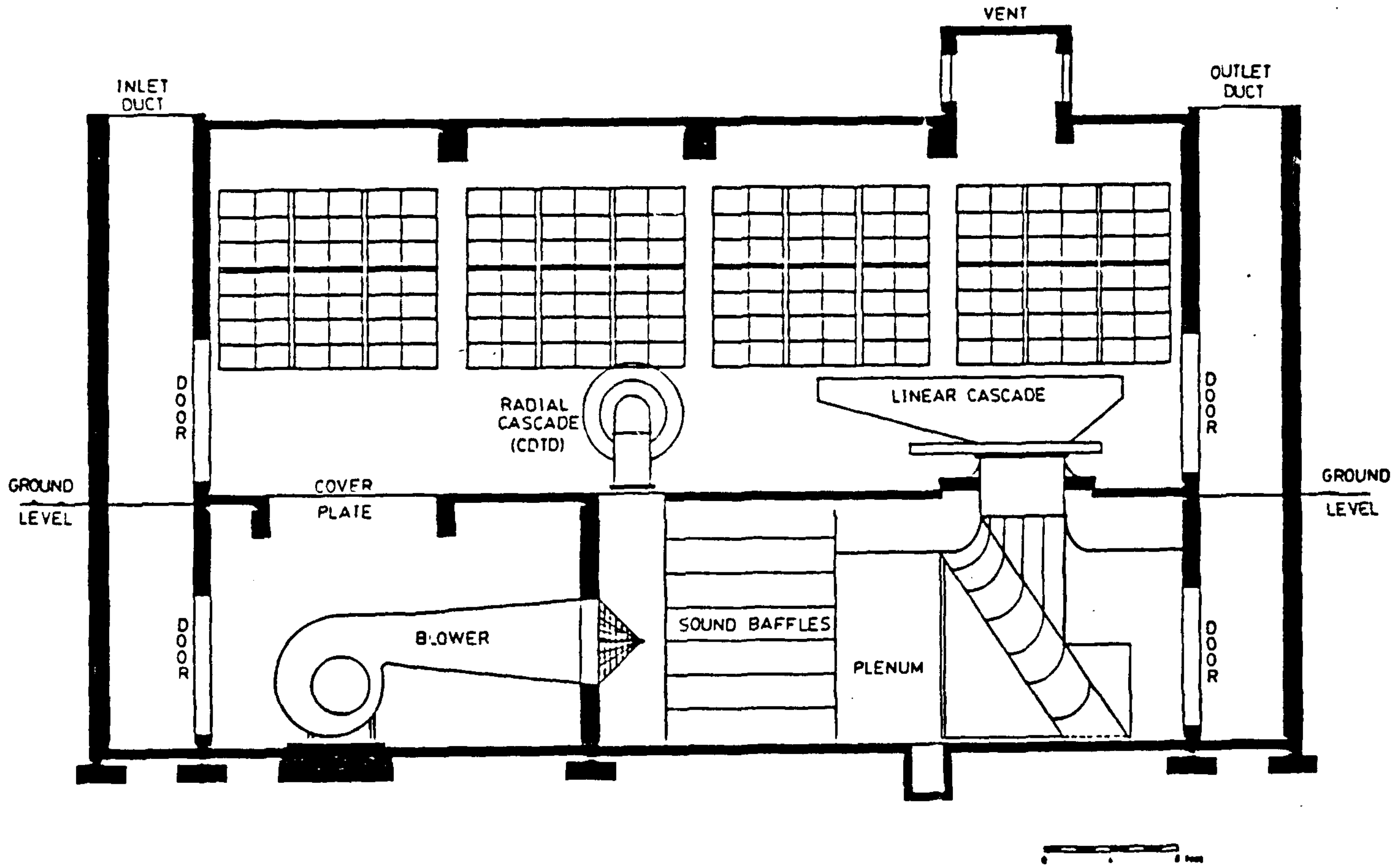


Figure 1. Linear Cascade Wind Tunnel Test Facility

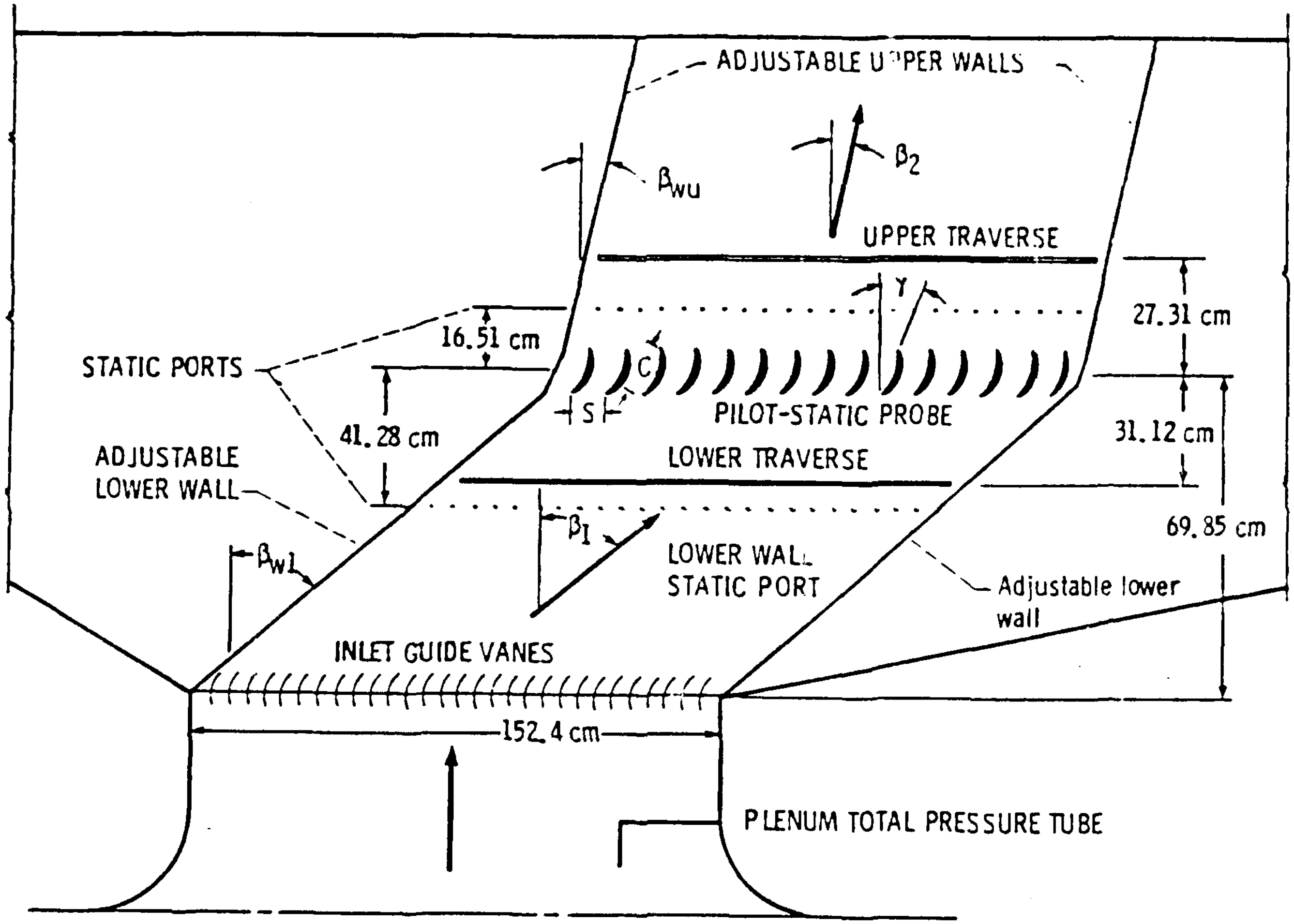
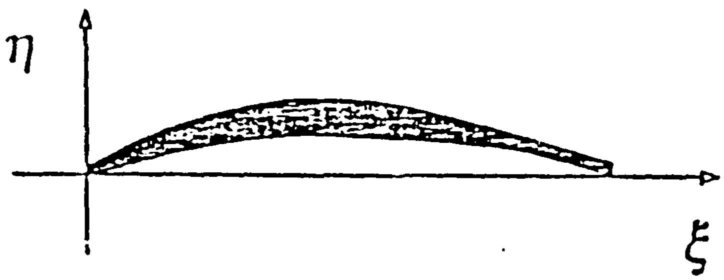


Figure 2. Cascade Test Section and Instrumentation

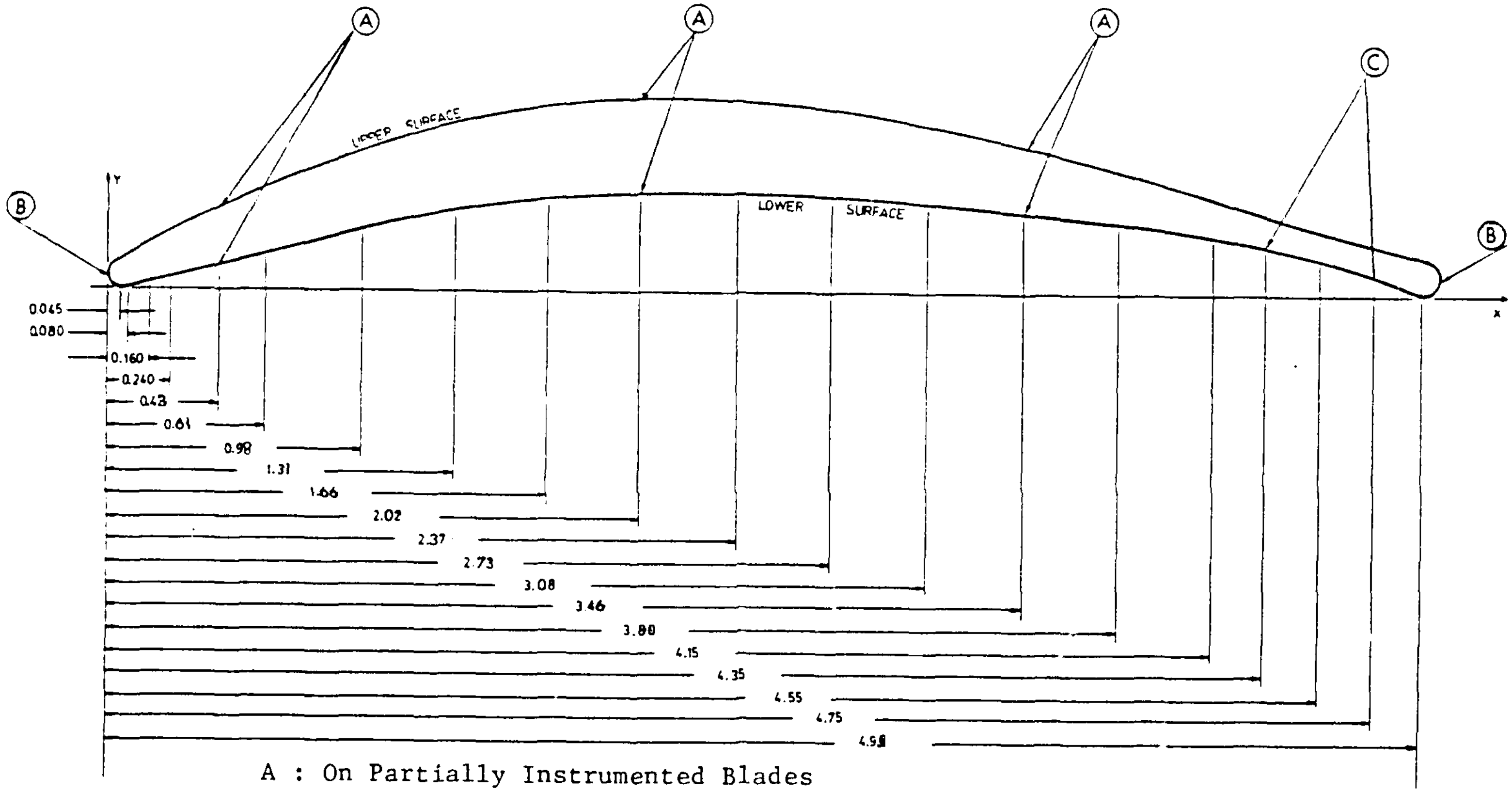
TABLE 1

BLADE GEOMETRY, CASCADE GEOMETRY AND NOMINAL TEST CONDITIONS



ξ (mm)	η (pressure side) (mm)	η (suction side) (mm)
0.000	0.114	0.114
0.056	———	0.213
0.145	0.005	———
0.564	0.112	0.498
1.128	0.257	0.780
1.692	0.394	1.024
2.256	0.526	1.240
2.819	0.648	1.425
3.383	0.759	1.577
3.947	0.838	1.684
4.511	0.889	1.755
5.075	0.912	1.791
5.639	0.912	1.798
6.203	0.894	1.781
6.767	0.869	1.730
7.330	0.841	1.651
7.894	0.805	1.549
8.458	0.765	1.430
9.022	0.714	1.295
9.586	0.653	1.151
10.150	0.577	0.998
10.714	0.485	0.843
11.278	0.371	0.686
11.841	0.226	0.528
12.405	0.048	0.368
12.510	0.010	———
12.609	———	0.310
12.725	0.157	0.157

Blade Type	Controlled Diffusion
Number of Blades	20
Blade Spacing	7.62 cm
Chord	12.73 cm
Solidity	1.67
Leading Edge Radius	0.114 cm
Trailing Edge Radius	0.157 cm
Thickness	7%
Setting Angle	14.2 ° ± 0.1 °
Stagger Angle	14.4 ° ± 0.1 °
Span	25.40 cm
NOMINAL TEST CONDITIONS	
Reynolds No.(chord)	720,000
Inlet	
Total Temperature	294 K
Total Pressure	1.03 ATM
Mach Number	0.25
Exit	
Static Pressure	1.00 ATM

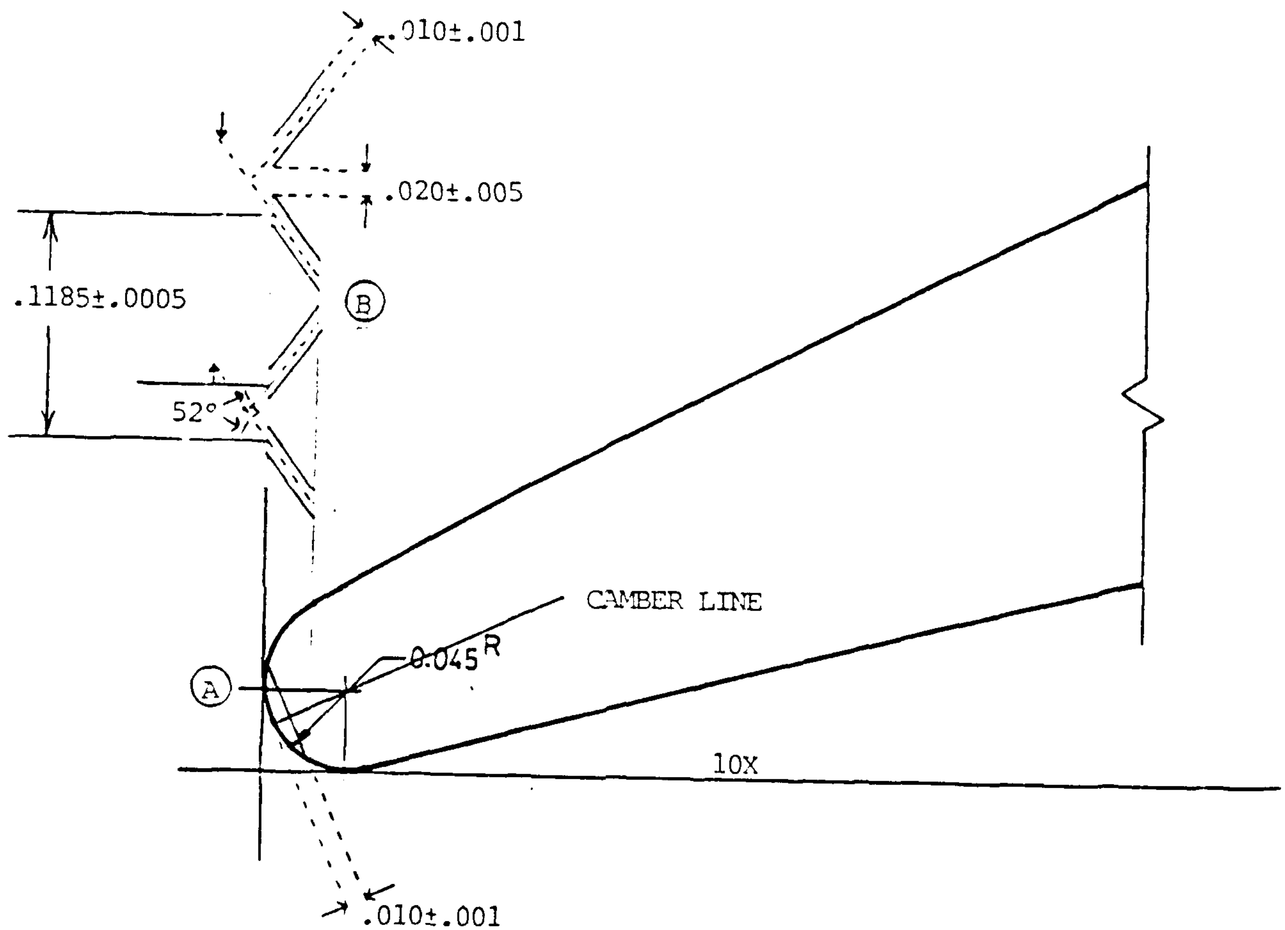


A : On Partially Instrumented Blades

B : Leading Edge Tap X =0.000 Y = 0.030
    Trailing Edge X =5.010 Y = 0.056

C : Upper Surface Only

Figure 3. Controlled Diffusion Blade Pressure Tap Locations



(A) Notch is perpendicular to the camber line

(B) Notch pairs are repeated entire leading edge

Figure 4. Slotted Controlled Diffusion Blade Leading Edge

Plenum thermocouple and pressure probes, Prandtl probe, wall static taps and instrumented blades were as described by Classick [Ref. 6].

Inlet and outlet flow angles were recorded using a yaw transducer mounted on the probe shaft. Probe sensor holes P2 and P5 shown in Figure 5 were used for yaw angle balancing, with a water manometer. The (linear) yaw transducer was zeroed in the vertical position and the span was set for the range to be measured.

A turn counter was mounted on the motor-driven traverse mechanism supporting the conical probe. The counter, which was recorded manually, provided the probe displacement in the blade-to-blade direction. A vernier scale on the probe mount, also recorded manually, gave the span-wise displacement.

D. DATA ACQUISITION SYSTEM

1. Hardware

Figure 6 shows a schematic of the data acquisition hardware used by Classick [Ref. 6] and in the present work, without any changes.

2. Software

a. ACQUIRE

Program ACQUIRE was used to control the data acquisition and store the collected data in memory. The program was unchanged from the work of Classick. Appendix B of Reference 6 contains the program flow chart and complete

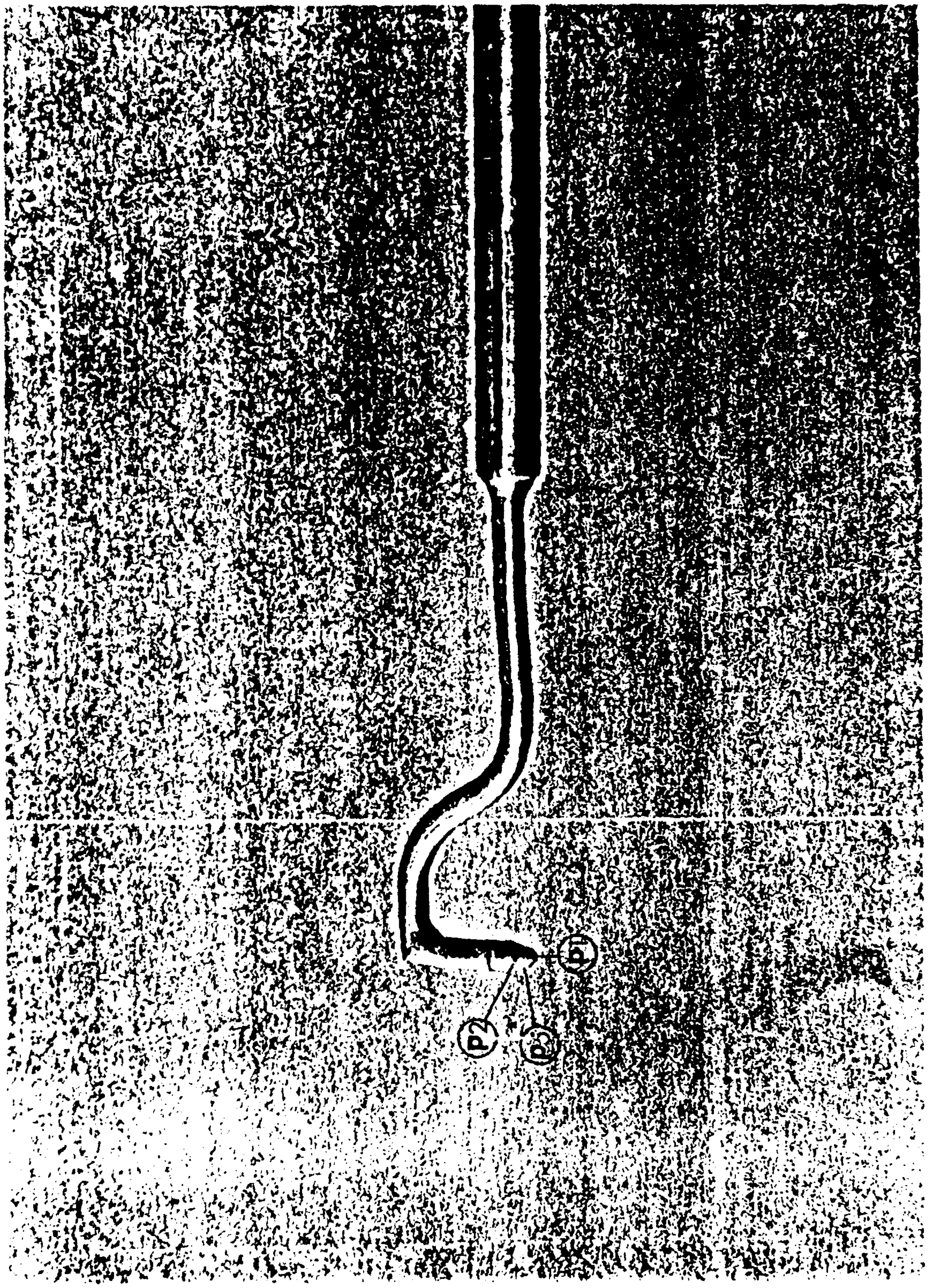


Figure 5. Five-hole Conical Probe

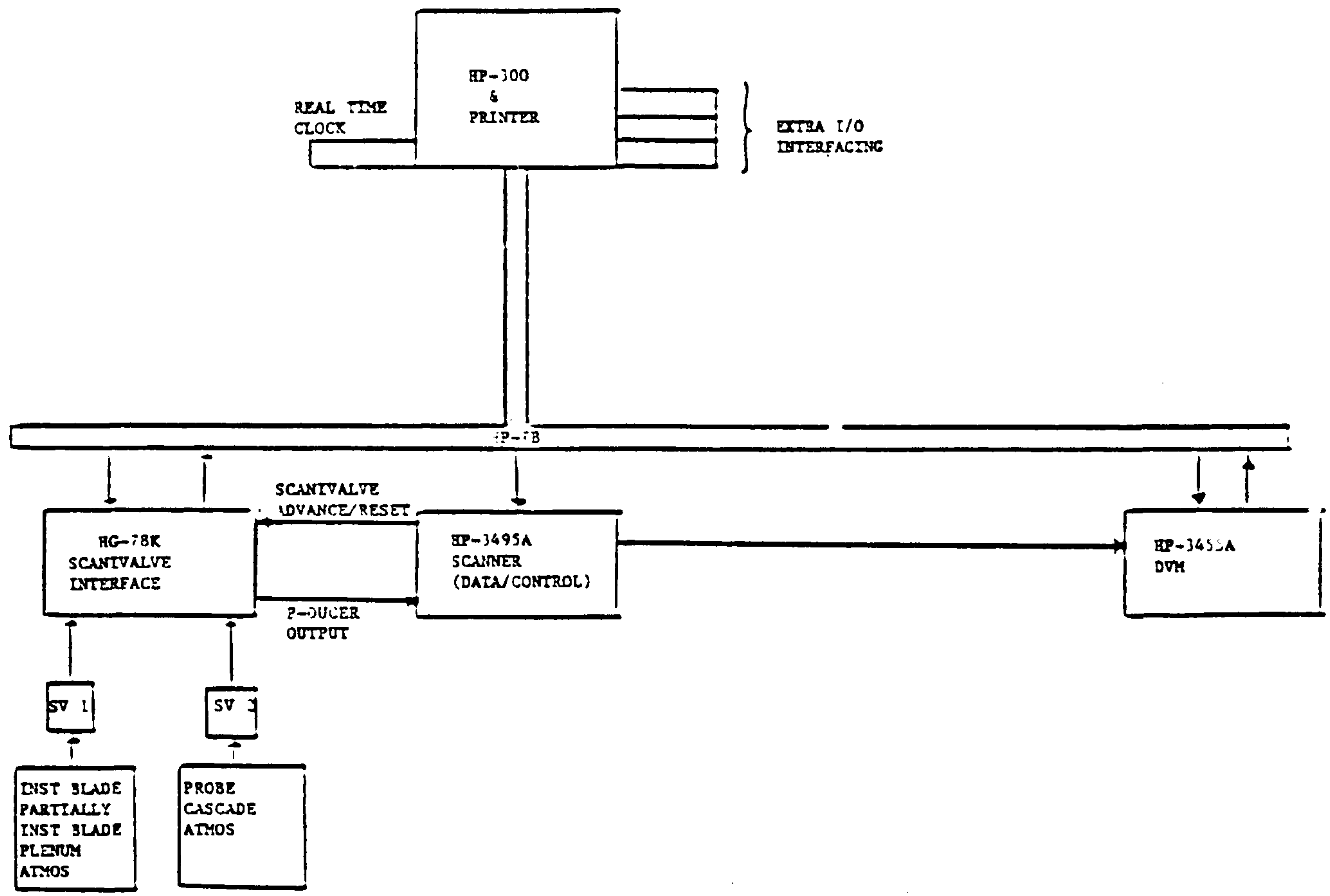


Figure 6. Data Acquisition System

listing. The listing is included in Table B13 of the present work.

b. CALC

Program CALC was used to reduce the data to engineering quantities and parameters to be used in the subsequent loss calculations. The flow of the program remained the same as in Classick's work. However, the program was modified to include calculation of the Reynolds number, provide yaw angle reference to the cascade through-flow direction and to provide additional parameters to pass to the program segment computing fully mixed-out losses. The revised listing and description of changes are given in Appendix B.

c. LOSS

Program LOSS was used to calculate the mass averaged and fully mixed-out losses for the test blade from the reduced data. The program was derived from the one developed by Classick. The mass averaged portion was not changed. Subroutine calls were added to calculate the mixed-out conditions for the upstream and downstream measurements and to calculate the loss based on the mixed-out conditions. Additional programming was included to provide the new output. Appendix B contains a complete listing of the program and associated routines.

III. TEST PROCEDURES AND PROGRAM OF MEASUREMENTS

A. TEST PROCEDURES

1. Setting Test Conditions

The inlet wall angle had been set previously at 48 degrees by Murray [Ref. 8]. A complete report of the angle setting procedures is given in Appendix A, Section VI of Reference 8. The inlet guide vanes were adjusted to ensure constant inlet flow angle in both span-wise and blade-to-blade directions. The adjustable upper walls were adjusted to obtain uniform wall static pressures in the blade-to-blade directions. All tests in the present study were conducted at a wall angle setting of 48 degrees and an inlet dynamic pressure (Q) nominally of 12.1 inches water. Atmospheric pressure was monitored and updated every hour of testing if necessary.

2. Calibration

Both Scanivalves were calibrated to give a digital output in engineering units, prior to each test, using a controlled source of shop air and a water manometer. The yaw was referenced perpendicular to the cascade blade row entry plane as described in Appendix F. Once this reference had been established, the yaw transducer was scaled at two known limits prior to each test, using a digital inclinometer.

3. Referencing

Tunnel inlet conditions at the time of recording were used to reference the pressure and velocity values obtained by reduction of probe test data at each survey point. This was done to eliminate the effects that small changes in the tunnel supply conditions might have on the calculation of the mass averaged loss coefficient (Duval [Ref. 9]) and the mixed-out loss coefficient (Appendix D).

4. Probe Surveys

Pressure probe surveys involved recording a data scan with the probe positioned at intervals varying from .05 to .6 inches. The surveys were conducted in span-wise directions across the tunnel and in blade-to-blade directions along the tunnel at the lower and upper traverse stations shown in Figure 2.

5. Measurement Uncertainties

The yaw angle was referenced and calibrated to ±.1 degree accuracy set by limitation of the digital inclinometer. The balancing uncertainty for the yaw angle was found to be ±.05 degree (equal to the variance when rebalancing with the probe in a fixed position after rotating the probe to introduce an imbalance). DVM fluctuations were minimized by using the average of five samples in the acquisition process, this had no effect on the accuracy of measurements. Scanivalve resolution was set to .001 inches of water with an estimated uncertainty of 0.02 inches of water of approximately

20 inches of water. Probe position in the blade-to-blade direction was measured using a counter with a resolution of ±.05 inches. Span-wise position was measured on a vernier with a resolution of ±.1 inches.

B. PROGRAM OF MEASUREMENTS

Probe surveys were conducted in the span-wise and blade-to-blade directions to establish the cascade inlet condition and the outlet flow fields behind the reference and slotted blade. Table 2 contains a summary of the probe surveys conducted, giving the survey number, the location, direction, interval and number of the figure in which the reduced data are shown plotted.

First, a set of probe surveys was conducted to establish the flow quality into the test section by spanning the entire 26 inches of traverse in the blade-to-blade direction. Second, an upstream survey of the reference blade was conducted in the blade-to-blade and span-wise directions. Third, a downstream survey of the reference blade was conducted in the blade-to-blade direction and in the span-wise direction. Finally, a downstream survey of the slotted blade was conducted in the blade-to-blade direction and in the span-wise direction. This final blade-to-blade survey encompassed two blade passages to provide data for the slotted blade and an adjacent reference blade.

TABLE 2

PROBE SURVEYS

SURVEY #	LOCATION	DIRECTION	NOMINAL INTERVAL	FIGURE
REFERENCE CASCADE:				
1	UPSTREAM	Blade-to-Blade (Blades 4-13)	.6 in	7,8,9
2	UPSTREAM	Span-wise (Blade 7)	.05-.1 in	11
3	UPSTREAM	Blade-to-Blade (Blade 7)	.1 in	10
4	DOWNSTREAM	Blade-to-Blade (Blade 7)	.05-.1 in	13a,14a, 15a
5	DOWNSTREAM	Span-wise (Blade 7--Suction)	.05-.1 in	16a,17a 18a
6	DOWNSTREAM	Span-wise (Blade 7--Pressure)	.05-.1 in	19a,20a 21a
WITH SLOTTED BLADE INSTALLED:				
7	DOWNSTREAM	Blade-to-Blade (Blades 7&8)	.05-.1 in	13b,14b 15b
8	DOWNSTREAM	Span-wise (Blade7--Suction)	.05-.1 in	16b,17b 18b
9	DOWNSTREAM	Span-wise (Blade 7--Suction)	.05-.1 in	19b,20b 21b

Upstream and downstream surveys were made at the traverse locations shown in Figure 2. The downstream span-wise surveys were located one inch from a vertical extension of the

trailing edge in both the suction and pressure directions. Measurement intervals were determined by the interval to be surveyed. The tunnel surveys required intervals of .6 inches. Upstream and downstream surveys were initially conducted at .1 inch intervals with the interval decreased to .05 inch intervals when a measurable change in the flow conditions was apparent. Instrumented blade surface pressure measurements were recorded at the end of each of the blade-to-blade surveys.

C. DATA REDUCTION AND PRESENTATION

The data collected were first scaled to engineering units and stored in a "scaled" file (Table B7, Appendix B). The scaled data were then reduced using the equations given in Table 3. The reduced data were stored in a "calc" file (Table B8, Appendix B). The "calc" file listing contains values of Scanivalve gauge pressures, yaw transducer reading, plenum temperature and atmospheric pressure. The ensemble averages given at the end of the files represent the nominal test conditions for the survey. Pressures are given in inches of water.

The "calc" file provided the inputs for loss measurement calculations. Figure B3, Appendix B is a program LOSS printout. Referring to Figure B3 the upper portion provides the name of the "calc" files used with the associated ensemble reference values of the reference velocity, plenum pressure

and atmospheric pressure. The intermediate values in the loss calculations using mass averaging follow, with the final results next. Mixed-out loss intermediate values are output next with the mixed out conditions of velocity, total pressure and static pressure preceding the calculated value of the mixed-out loss.

Appendix B of Reference 6 defines and describes the quantities Beta, Gamma and Phi which are listed in the "calc" files. Table 3 and the list of symbols define all other quantities in the "calc" files and loss printouts.

TABLE 3

DATA REDUCTION FORMULAE

PARAMETER	EXPRESSION	PROGRAMMED EXPRESSION
X	$\left[\dfrac{\frac{\gamma-1}{2} M^2}{1 + \frac{\gamma-1}{2} M^2}\right]^{1/2}$	same
X_{ref}	$\left[1 - \left(\dfrac{P_a}{P_p}\right)^{\frac{\gamma-1}{\gamma}}\right]^{1/2}$	same
$\hat{X}_{ref}$	$\left[1 - \left(\dfrac{P_a}{\hat{P}_b}\right)^{\frac{\gamma-1}{\gamma}}\right]^{1/2}$	same
P_s	$P_t(1 - X^2)^{\frac{\gamma}{\gamma-1}}$	same
P_s ratio	$P_t \text{ ratio}(1 - X_{mix}^2)^{\frac{\gamma}{\gamma-1}}$	same
P_t ratio	$\dfrac{\hat{X}_p}{X_{mix}} \dfrac{(1-\hat{X}_p^2)^{\frac{\gamma}{\gamma-1}}}{(1-X_{mix}^2)^{\frac{\gamma}{\gamma-1}}} \dfrac{\hat{I}1}{\cos \beta_{mix}}$	same
$\hat{P}_p$	$\dfrac{1}{n} \sum_{r=1}^{n} P_p$	same

TABLE 3 (CONTINUED)

$\hat{T}_p$	$\frac{1}{n}\sum_{n=1}^{n} T_p$	same
V	$X(2\ C_p\ T_p)^{1/2}$	$X(2C_p(778)(32.174)T_p)^{1/2}$
V_{ref}	$X_{ref}(2\ C_p\ T_p)^{1/2}$	$X_{ref}(2C_p(778)(32.174)T_p)^{1/2}$
$\hat{V}_{ref}$	$\hat{X}_{ref}(2\ C_p\ \hat{T}_p)^{1/2}$	$\hat{X}_{ref}(2C_p(778)(32.174)\hat{T}_p)^{1/2}$
Q	$P_t(\frac{\gamma}{\gamma-1})X^2(1-X^2)^{\frac{1}{\gamma-1}}$	same
Q_{ref}	$P_p(\frac{\gamma}{\gamma-1})X_{ref}^2(1-X_{ref}^2)^{\frac{1}{\gamma-1}}$	same
$\hat{Q}_{ref}$	$\hat{P}_p(\frac{\gamma}{\gamma-1})\hat{X}_{ref}^2(1-\hat{X}_{ref}^2)^{\frac{1}{\gamma-1}}$	same
$\hat{I}1$	$\int_0^1 \frac{P_t}{P_{tref}}\frac{X}{X_{ref}}\frac{(1-X^2)^{\frac{1}{\gamma-1}}}{(1-X_{ref}^2)^{\frac{1}{\gamma-1}}}\cos\beta\ d(\frac{x}{S})$	same
$\hat{I}2$	$\int_0^1 \frac{P_t}{P_{tref}}\frac{X^2}{X_{ref}^2}\frac{(1-X^2)^{\frac{1}{\gamma-1}}}{(1-X_{ref}^2)^{\frac{1}{\gamma-1}}}\cos\beta\sin\beta d(\frac{x}{S})$	same

TABLE 3 (CONTINUED)

$\hat{I}3$	$\int_0^1 \frac{P_t}{P_{tref}} \frac{[(1-X^2)^{\frac{\gamma}{\gamma-1}} + (\frac{2\gamma}{\gamma-1})X^2(1-X^2)^{\frac{1}{\gamma-1}}\cos^2\beta_2]d(\frac{X}{S})}{[X_{ref}^2(1-X_{ref}^2)^{\frac{1}{\gamma-1}}]}$	
$\hat{A}$	$\hat{X}_{ref} \frac{\hat{I}_2}{\hat{I}_1}$	same
$\hat{B}$	$\hat{X}_{ref} \frac{\hat{I}_3}{\hat{I}_1}$	same
$\hat{C}$	$(\frac{\gamma+1}{\gamma-1})^2$	same
$\hat{D}$	$2(\frac{\gamma+1}{\gamma-1})(1 - \frac{2\gamma}{\gamma-1})\hat{A}^2 - \hat{B}^2$	same
$\hat{E}$	$(1 - \frac{2\gamma}{\gamma-1}\hat{A}^2)^2 + \hat{B}^2\hat{A}^2$	same
K	$\frac{P_t}{P_p} \frac{X}{X_{ref}} \left[\frac{1-X^2}{1-X_{ref}^2}\right]^{\frac{1}{\gamma-1}} \cos\beta$	same
AVDR	$\frac{h_1}{h_2}$	$\frac{\int_0^S K_2\,dx}{\int_0^2 K_1\,dx}$

TABLE 3 (CONTINUED)

C_{pt}	$\dfrac{P_t}{P_p}$	same
C_{ps}	$\dfrac{P_s}{P_p}$	same
$\overline{C}_p$	$\dfrac{P_\ell - P_a}{P_p - P_a}\ \overline{\left(\dfrac{P_p - P_a}{Q}\right)} + \overline{\left(\dfrac{P_a - P_s}{Q}\right)}$	$\left(\dfrac{P_\ell - P_a}{P_p - P_s}\right) \dfrac{\int_0^S \dfrac{P_p - P_a}{Q} K_\ell\, dx}{\int_0^S K_\ell\, dx} + \dfrac{\int_0^S \dfrac{P_a - P_s}{Q}\, dx}{\int_0^S K_\ell\, dx}$
C_{p2}	$\overline{\left(\dfrac{P_{su} - P_a}{Q}\right)} + \left(\dfrac{P_a - P_{s\ell}}{Q}\right)$	$\dfrac{\int_0^S \dfrac{P_{su} - P_a}{Q} K_\ell\, dx}{\int_0^S K_\ell\, dx} + \dfrac{\int_0^S \dfrac{P_a - P_{s\ell}}{Q}\, dx}{\int_0^S K_\ell\, dx}$
C_{p3}	$\overline{\left(\dfrac{P_{sumix} - P_a}{Q}\right)} + \overline{\left(\dfrac{P_a - P_{s\ell mix}}{Q}\right)}$	$\int_0^1 \dfrac{P_{sumix} - P_a}{Q}\, dx + \int_0^1 \dfrac{P_a - P_{s\ell mix}}{Q}\, dx$
ω	$\dfrac{\overline{C}_{pt\ell} - \overline{C}_{ptu}}{\overline{C}_{pt\ell} - \overline{C}_{ps\ell}}$	$\dfrac{\int_0^S C_{pt\ell} K_\ell\, dx - \dfrac{1}{AVDR} \int_0^S C_{ptu} K_u\, dx}{\int_0^S C_{pt\ell} K_\ell\, dx - \int_0^S C_{ps\ell} K_\ell\, dx}$

TABLE 3 (CONTINUED)

ω_{mx}	$$\frac{\frac{P_{t\ell mix}}{\hat{P}_{ref}} - \frac{P_{tumix}}{\hat{P}_{ref}}}{\frac{P_{t\ell mix}}{\hat{P}_{ref}} - \frac{P_{s\ell mix}}{\hat{P}_{ref}}}$$	same
$X^2 mix$	$$\frac{-\hat{D} \pm \sqrt{\hat{D}^2 - 4\hat{C}\hat{E}}}{2\hat{C}}$$	same
βmix	$$\sin^{-1} \left(\frac{\hat{A}}{X_{mix}}\right)$$	same

IV. RESULTS AND DISCUSSION

The results are presented first for the upstream flow field in Figures 7-11. Blade 10 and the adjacent blade surface pressures are shown in Figure 12. The probe surveys downstream of blade 7 are shown in Figures 13-21, with section (a) of each figure giving the reference case and section (b) giving results with the slotted blade installed. Losses are given in Figure 22 and the loss distribution for the reference and slotted blade wakes is shown in Figure 23. Finally, surface flow visualization sketches are given in Figure 24.

A. FLOW FIELD

1. Upstream Flow Field

The inlet flow field, spanning eight to nine blade spaces, is shown in Figures 7-9. Deviations from a fully uniform velocity were due to persistence of inlet guide vane wakes and to slight non-uniformities in the vane passage geometries. The inlet conditions in the survey region of blade seven, where the present testing was based, was acceptably uniform in the blade-to-blade direction as shown in Figures 7 to 9 and in Figure 10, which shows the results of the detailed upstream survey. The inlet flow conditions in

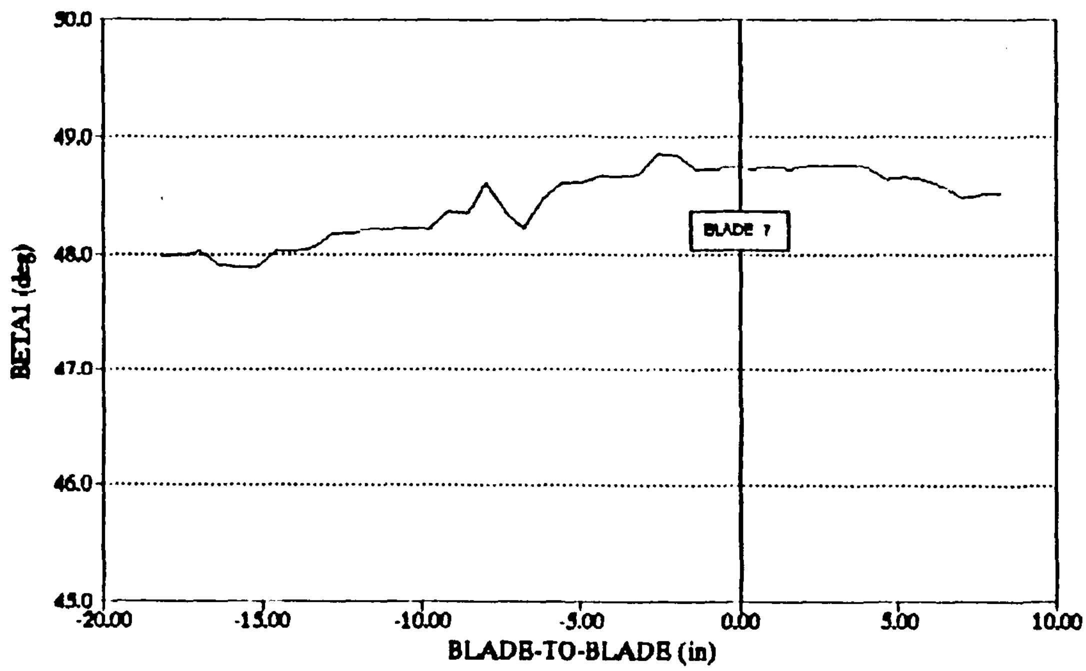


Figure 7. Tunnel Inlet Survey: Beta vs. Probe Displacement, Blade-to-Blade

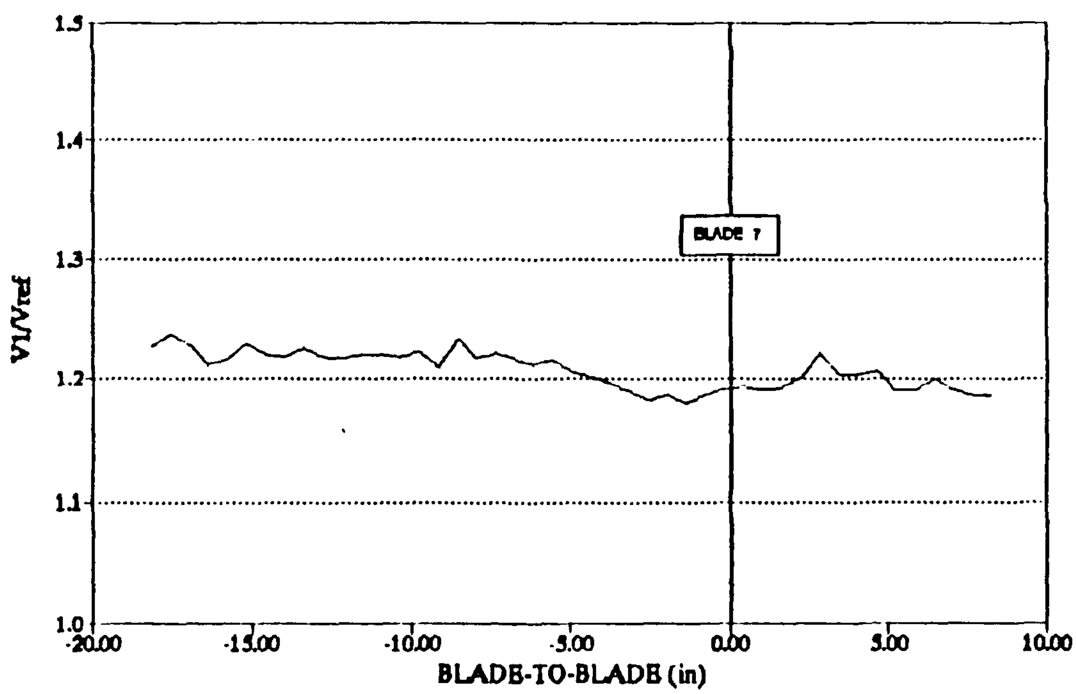


Figure 8. Tunnel Inlet Survey: V1/Vref vs. Probe Displacement, Blade-to-Blade

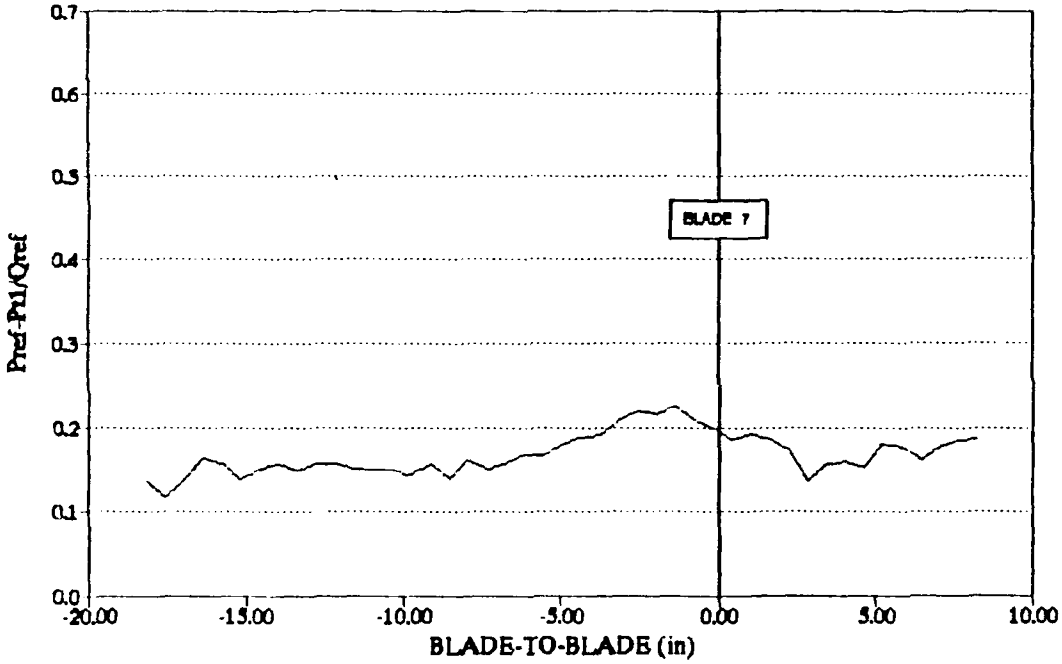


Figure 9. Tunnel Inlet Survey: Pref-Pt1/Qref vs. Probe Displacement, Blade-to-Blade

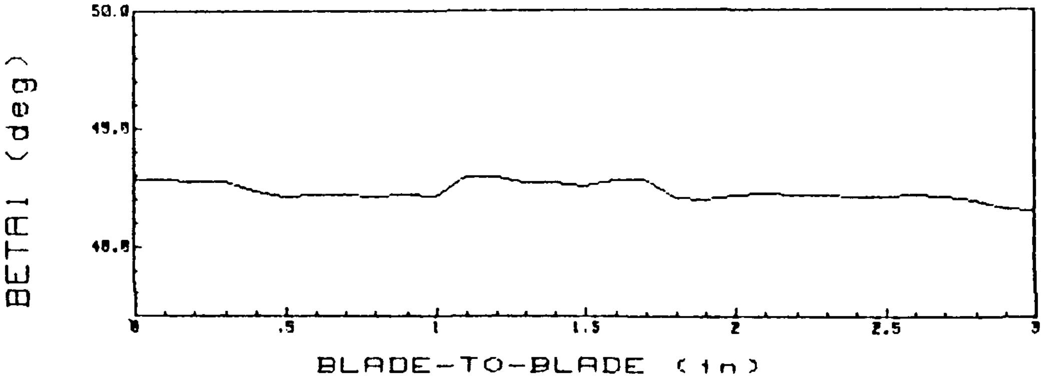


Figure 10a. Reference Blade Upstream Survey: Beta vs. Probe Displacement, Blade-to-Blade

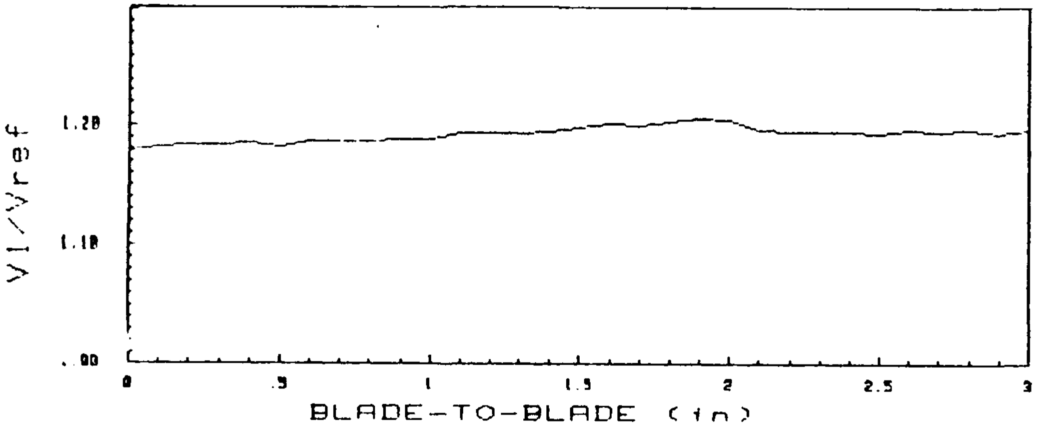


Figure 10b. Reference Blade Upstream Survey: V1/Vref vs. Probe Displacement, Blade-to-Blade

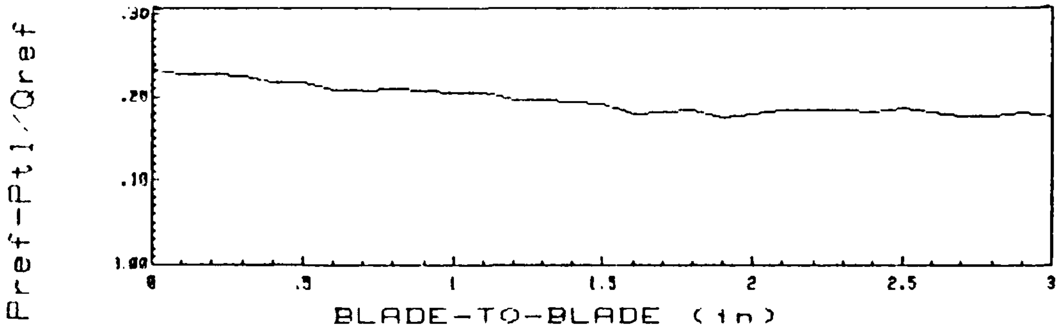


Figure 10c. Reference Blade Upstream Survey: Pref-Pt1/Qref vs. Probe Displacement, Blade-to-Blade

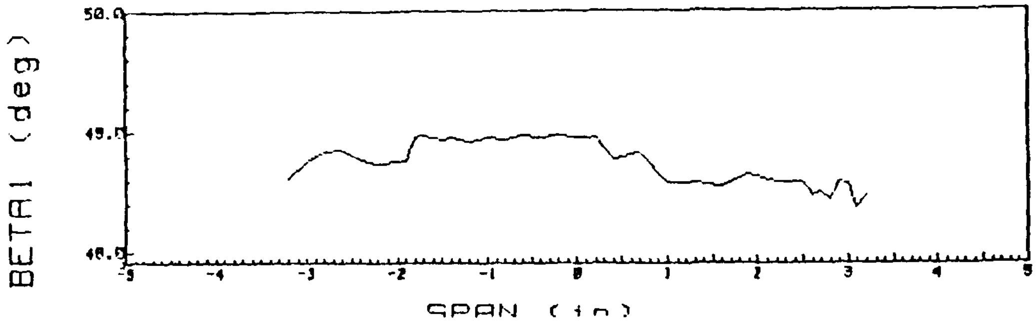


Figure 11a. Reference Blade Upstream Survey: Beta vs. Probe Displacement, Span-wise

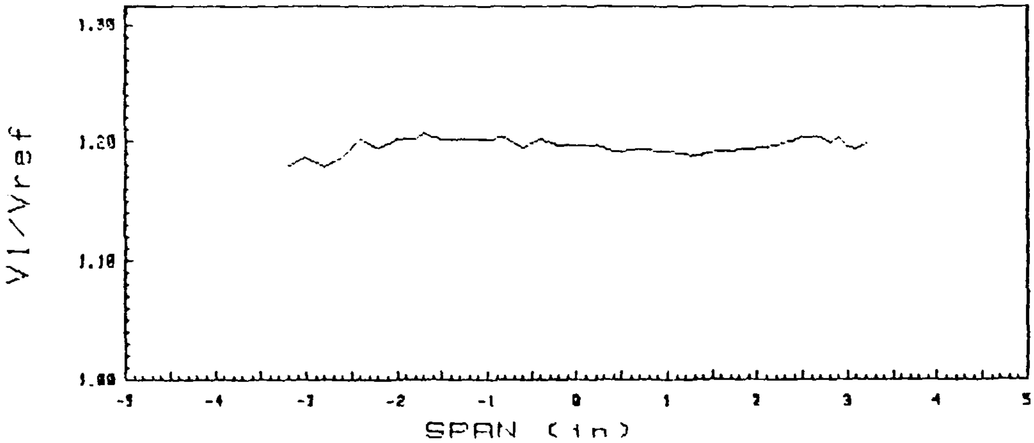


Figure 11b. Reference Blade Upstream Survey: V1/Vref vs. Probe Displacement, Span-wise

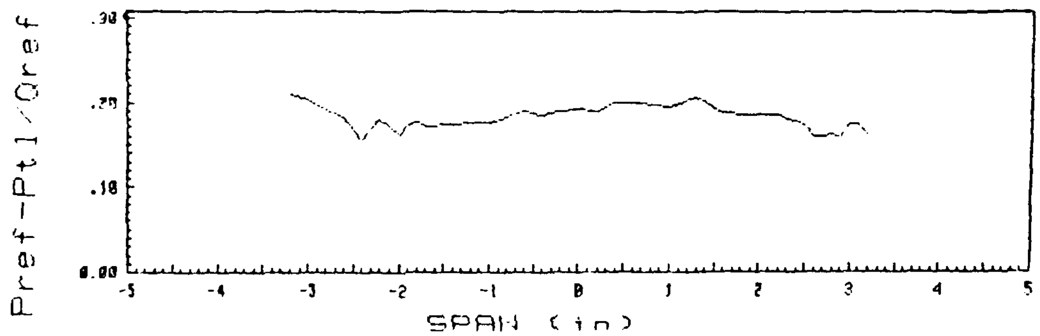


Figure 11c. Reference Blade Upstream Survey: Pref-Pt1/Qref vs. Probe Displacement, Span-wise

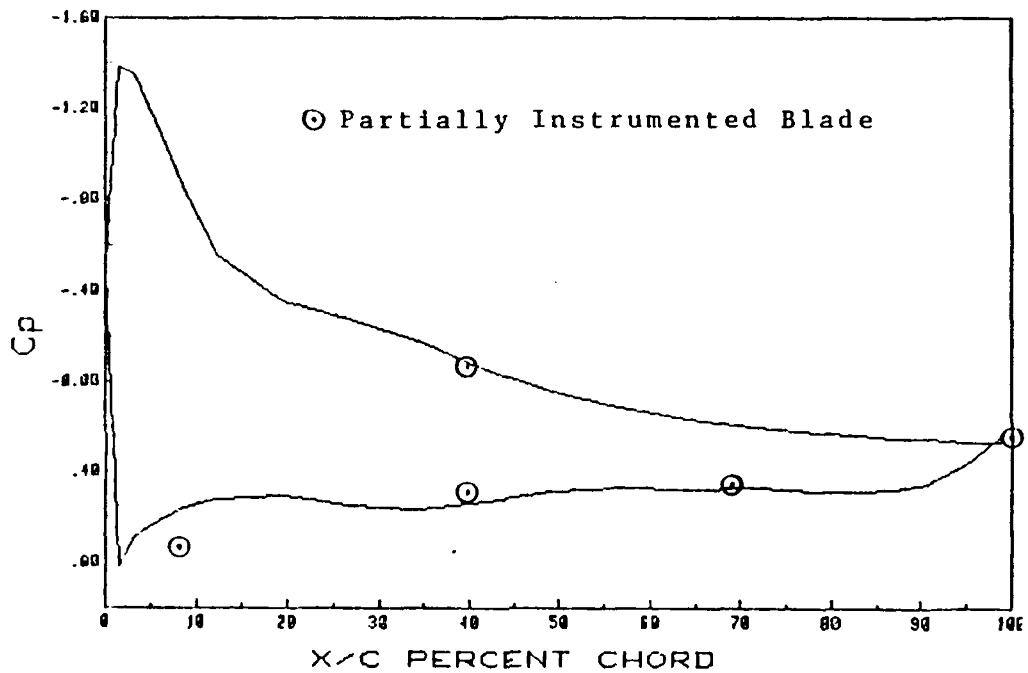


Figure 12. Surface Pressure Distribution: Cp vs. X/C

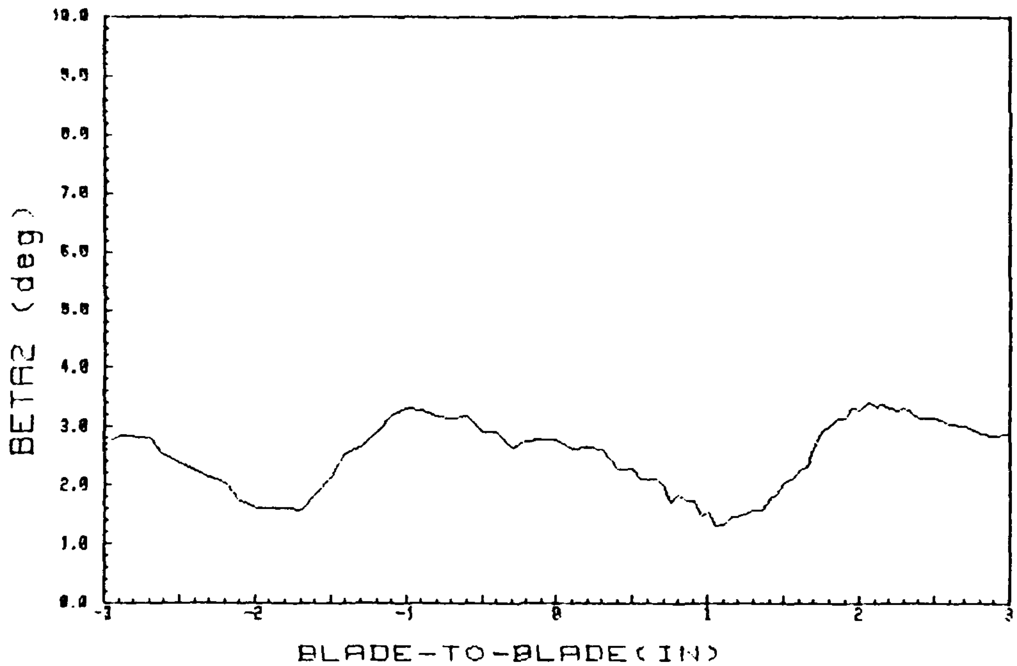


Figure 13a. Reference Blade Downstream Survey: Beta vs. Probe Displacement, Blade-to-Blade

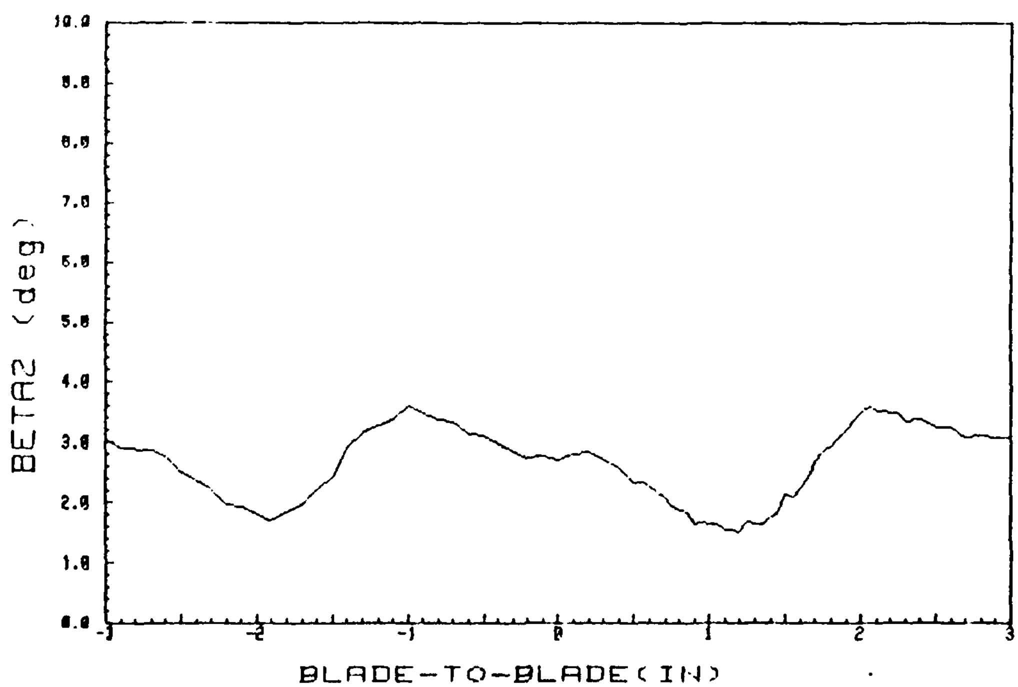


Figure 13b. Slotted Blade Downstream Survey: Beta vs. Probe Displacement, Blade-to-Blade

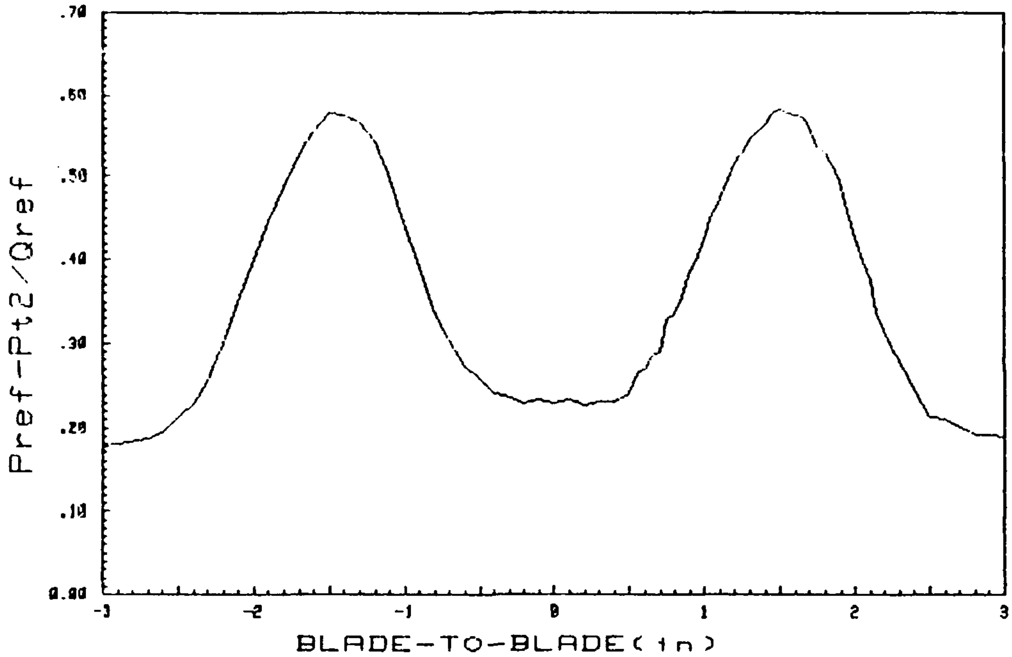


Figure 14a. Reference Blade Downstream Survey: Pref-Pt2/ Qref vs. Probe Displacement, Blade-to-Blade

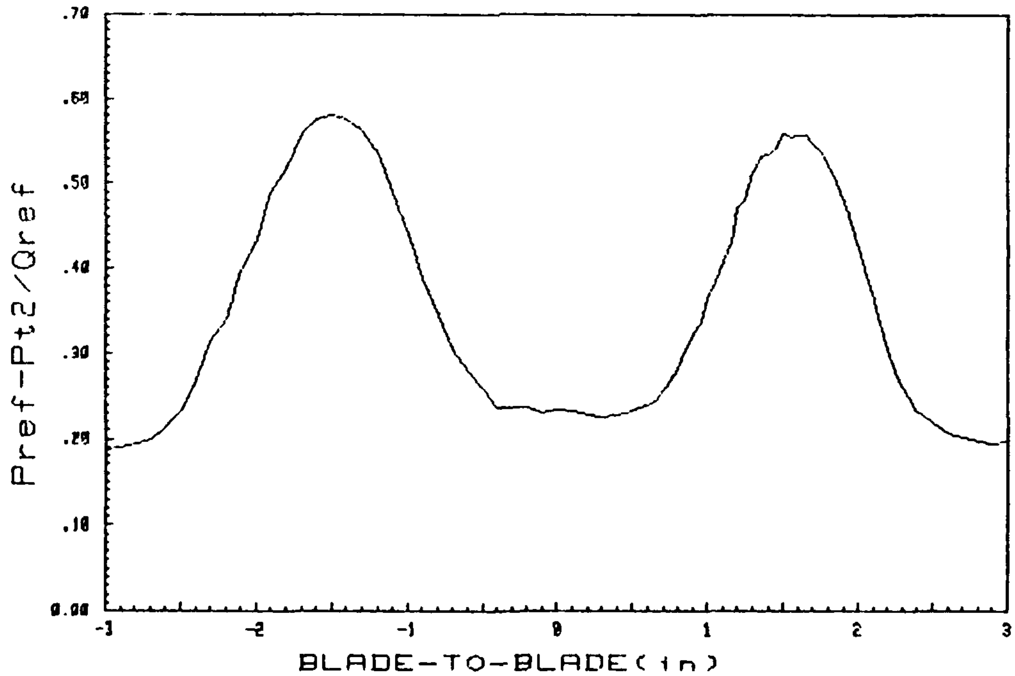


Figure 14b. Slotted Blade Downstream Survey: Pref-Pt2/Qref vs. Probe Displacement, Blade-to-Blade

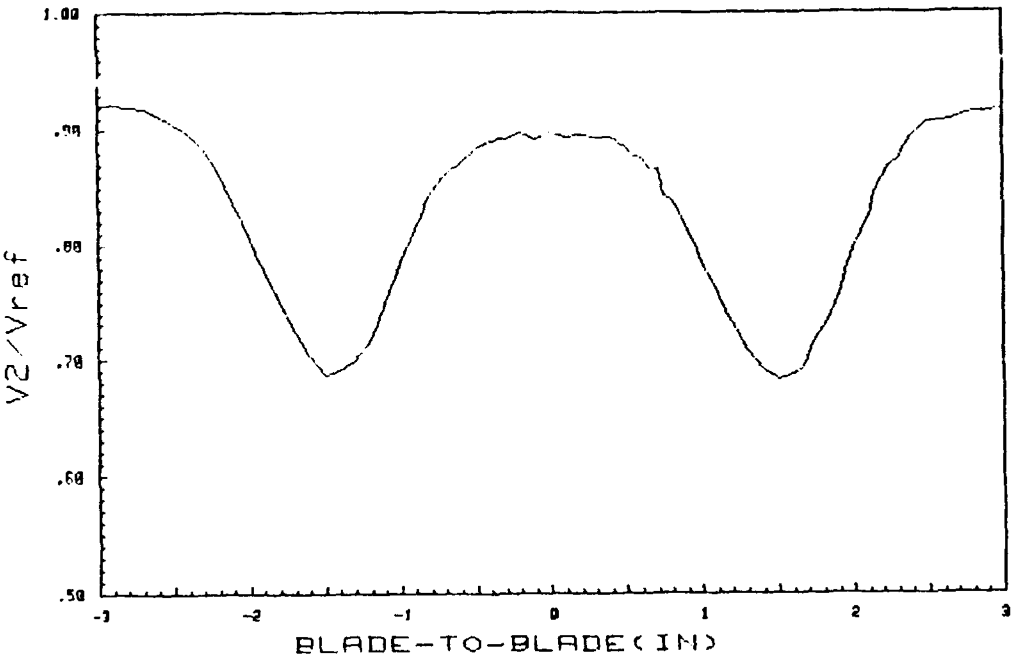


Figure 15a. Reference Blade Downstream Survey: V2/Vref vs. Probe Displacement, Blade-to-Blade

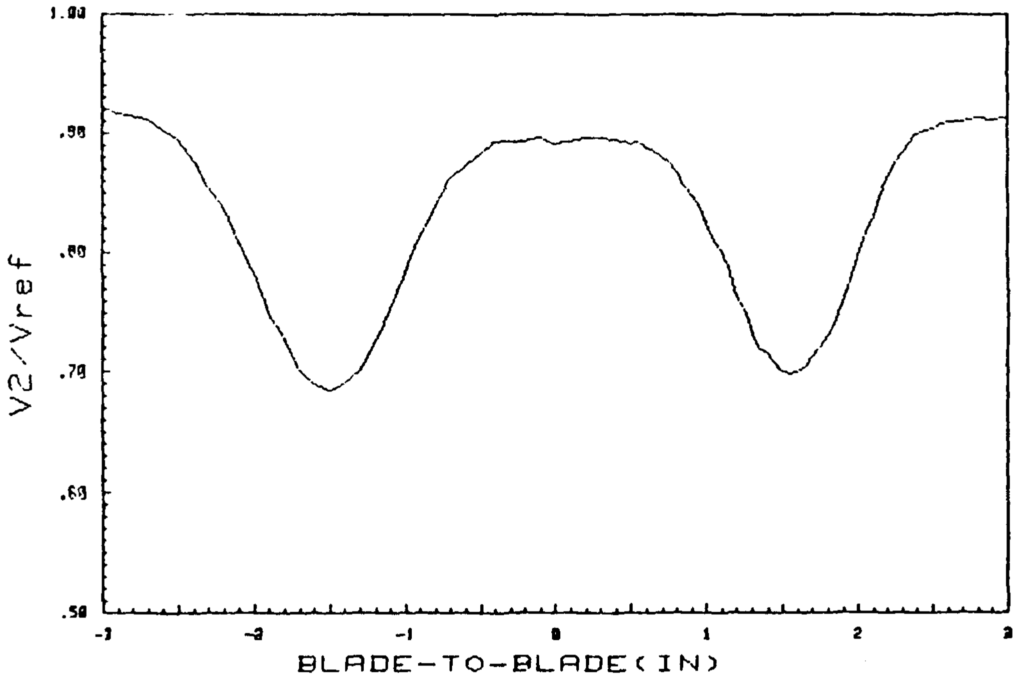


Figure 15b. Slotted Blade Downstream Survey: V2/Vref vs. Probe Displacement, Blade-to-Blade

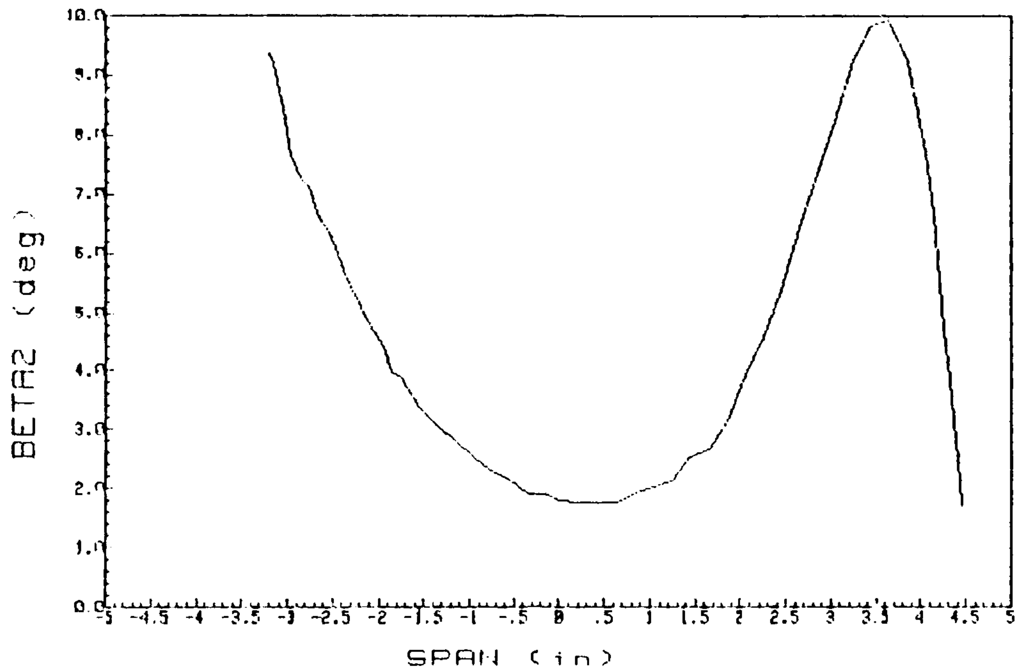


Figure 16a. Reference Blade Downstream Survey: Beta vs. Probe Displacement, Span-wise, Suction Side

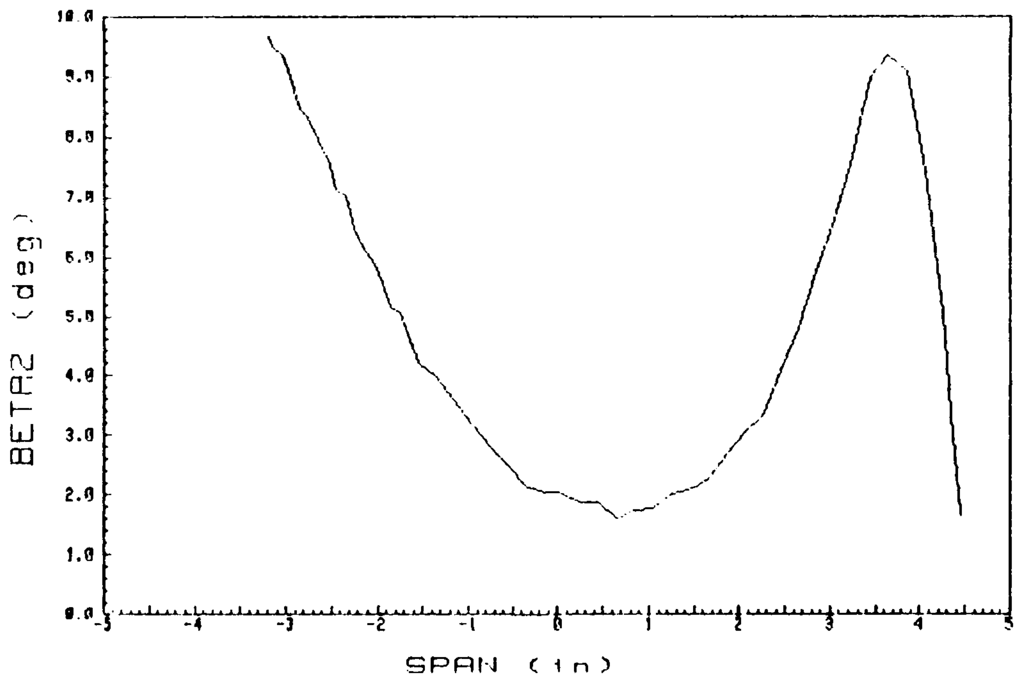


Figure 16b. Slotted Blade Downstream Survey: Beta vs. Probe Displacement, Span-wise, Suction Side

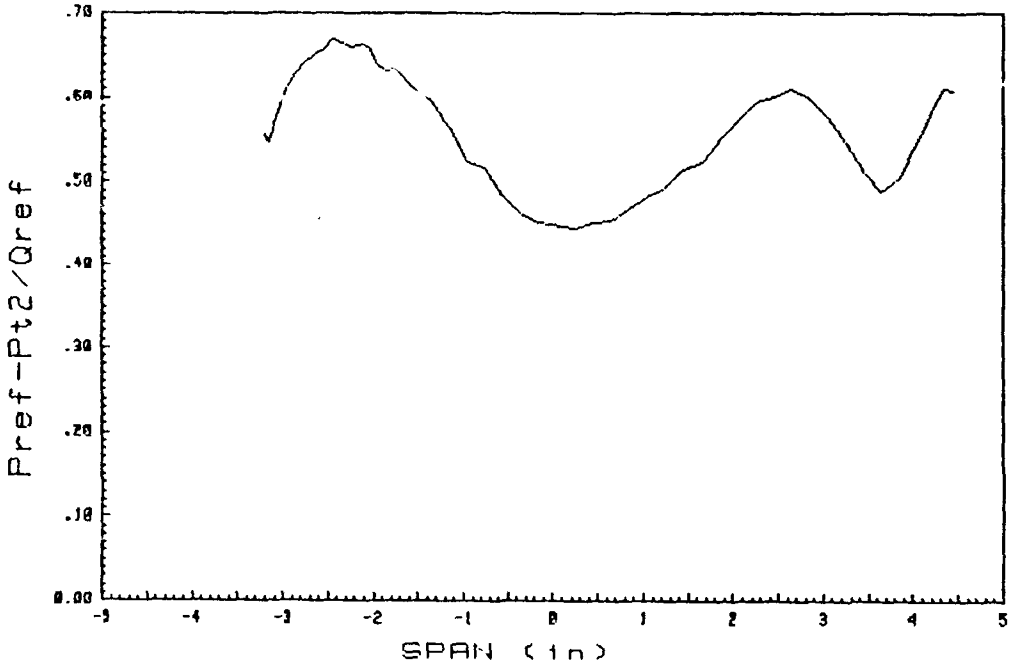


Figure 17a. Reference Blade Downstream Survey: Pref-Pt2/Qref vs. Probe Displacement, Span-wise, Suction Side

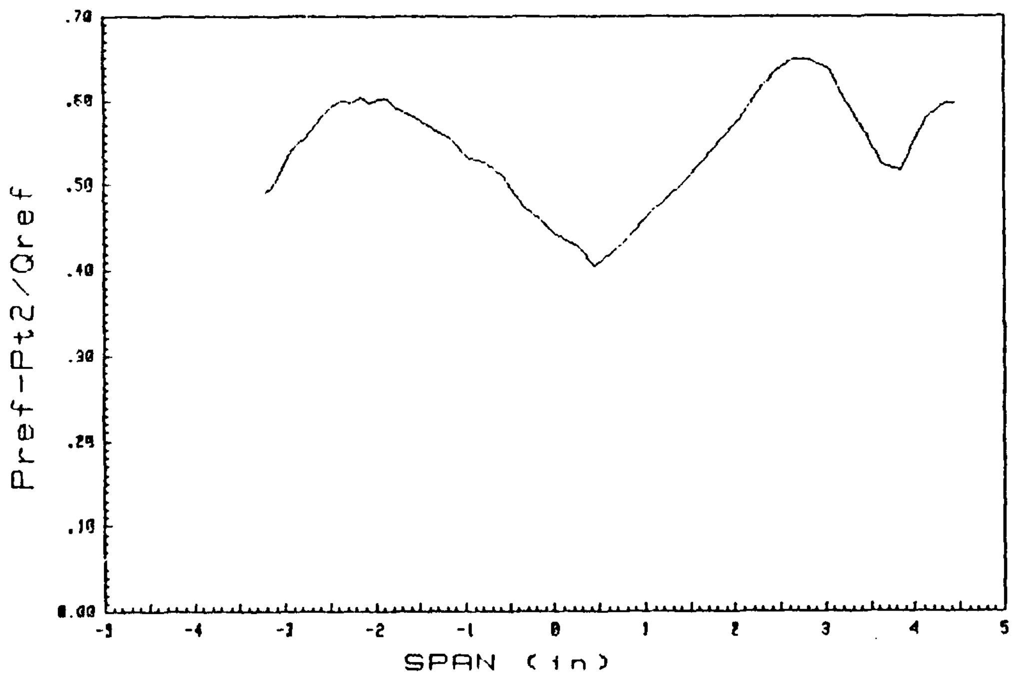


Figure 17b. Slotted Blade Downstream Survey: Pref-Pt2/Qref vs. Probe Displacement, Span-wise, Suction Side

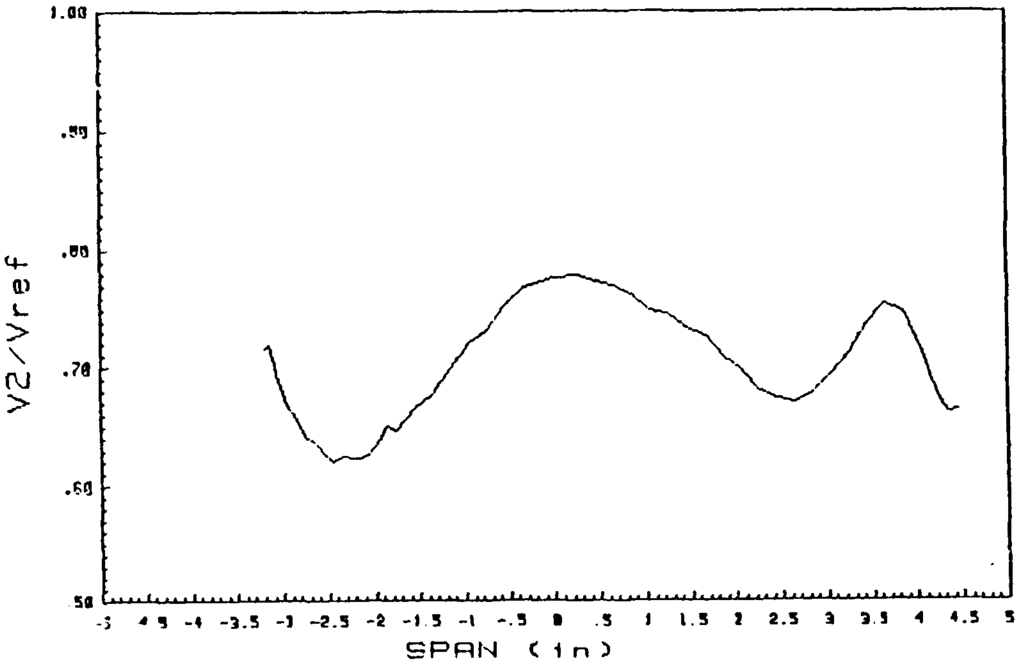


Figure 18a. Reference Blade Downstream Survey: V2/Vref vs. Probe Displacement, Span-wise, Suction Side

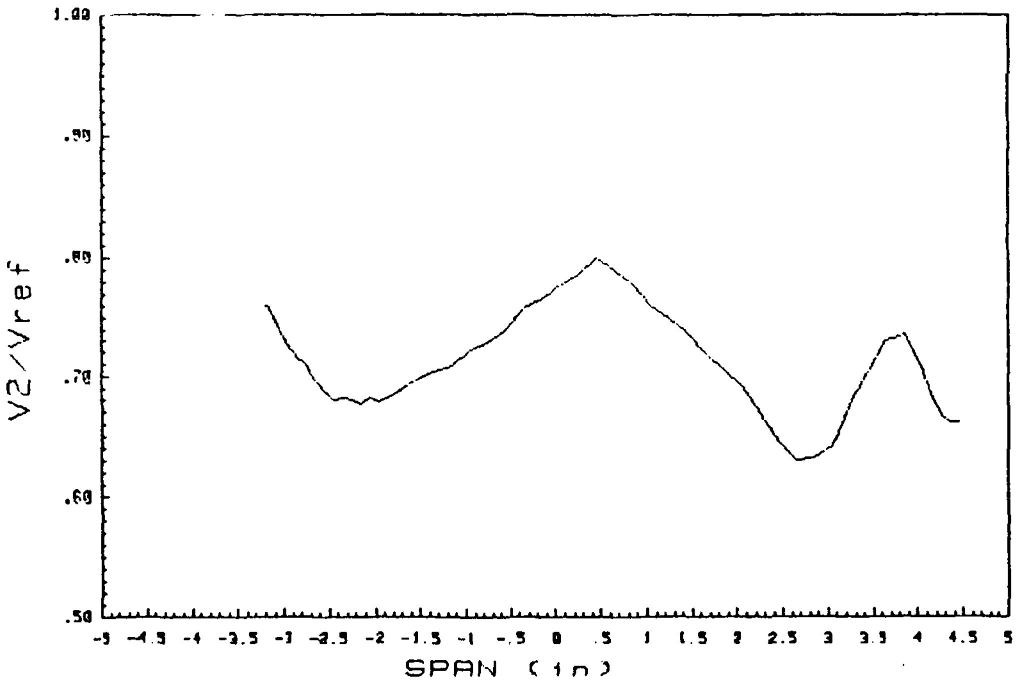


Figure 18b. Slotted Blade Downstream Survey: V2/Vref vs. Probe Displacement, Span-wise, Suction Side

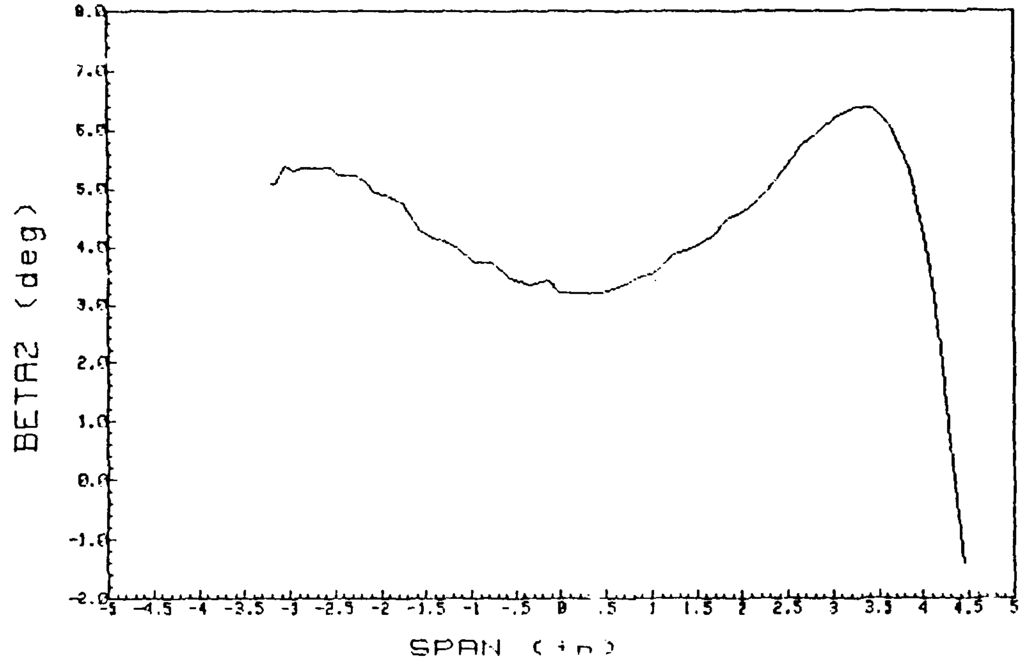


Figure 19a. Reference Blade Downstream Inlet Survey: Beta vs. Probe Displacement, Span-wise, Pressure Side

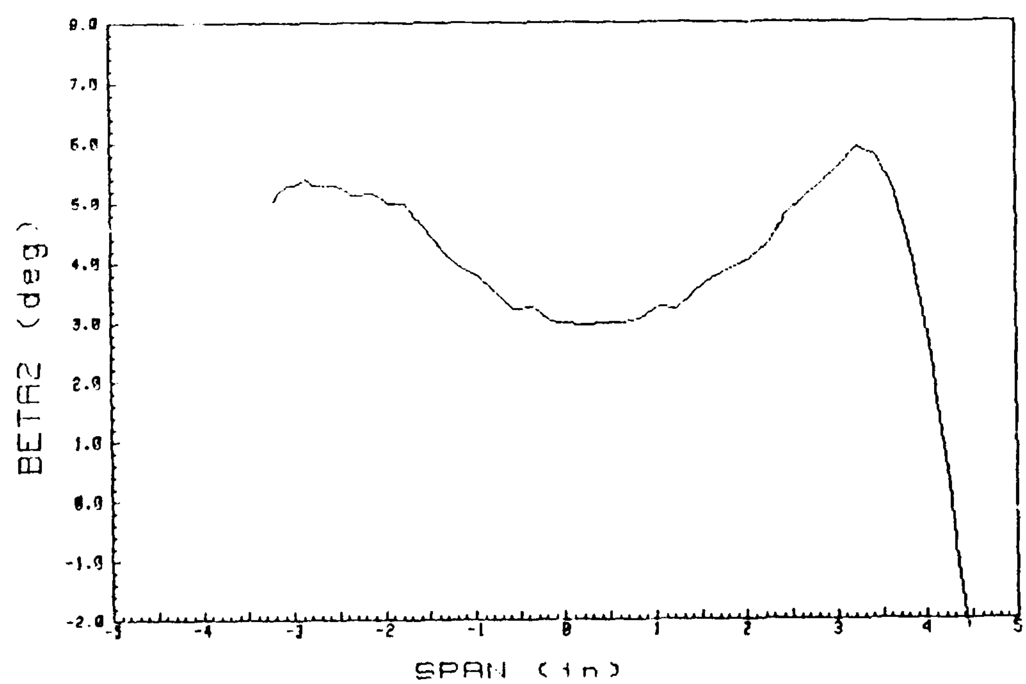


Figure 19b. Slotted Blade Downstream Survey: Beta vs. Probe Displacement, Span-wise, Pressure Side

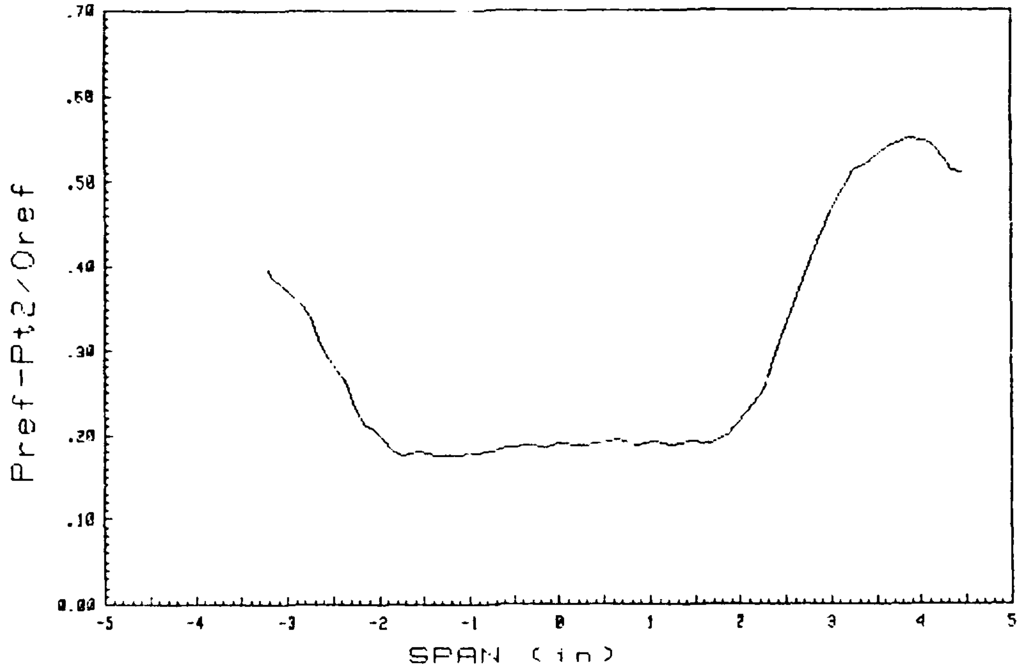


Figure 20a. Reference Blade Downstream Survey: Pref-Pt2/Qref vs. Probe Displacement, Span-wise, Pressure Side

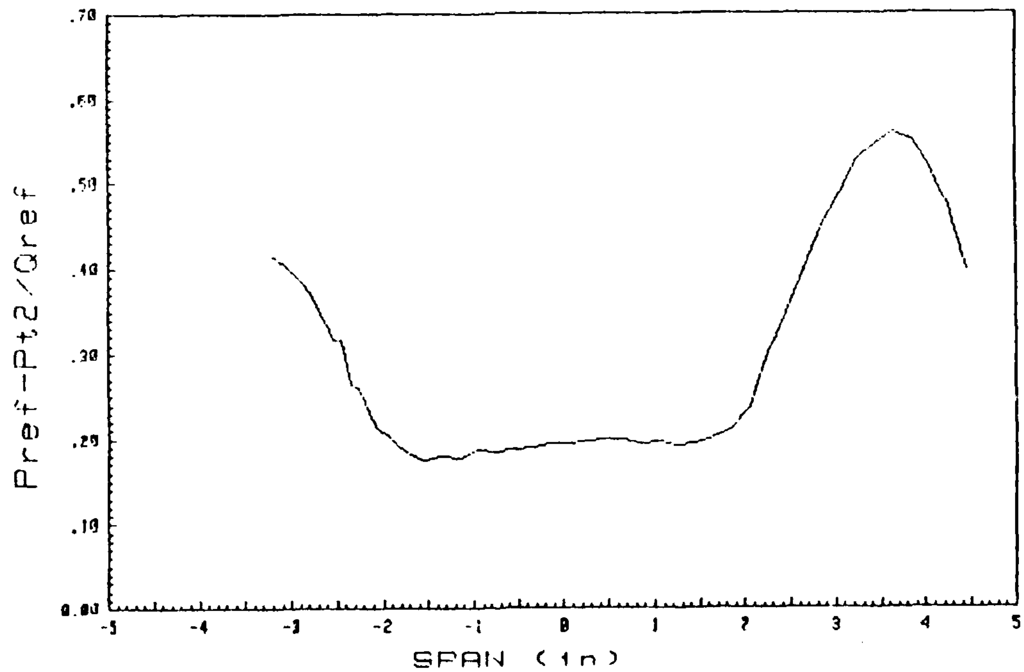


Figure 20b. Slotted Blade Downstream Survey: Pref-Pt2/Qref vs. Probe Displacement, Span-wise, Pressure Side

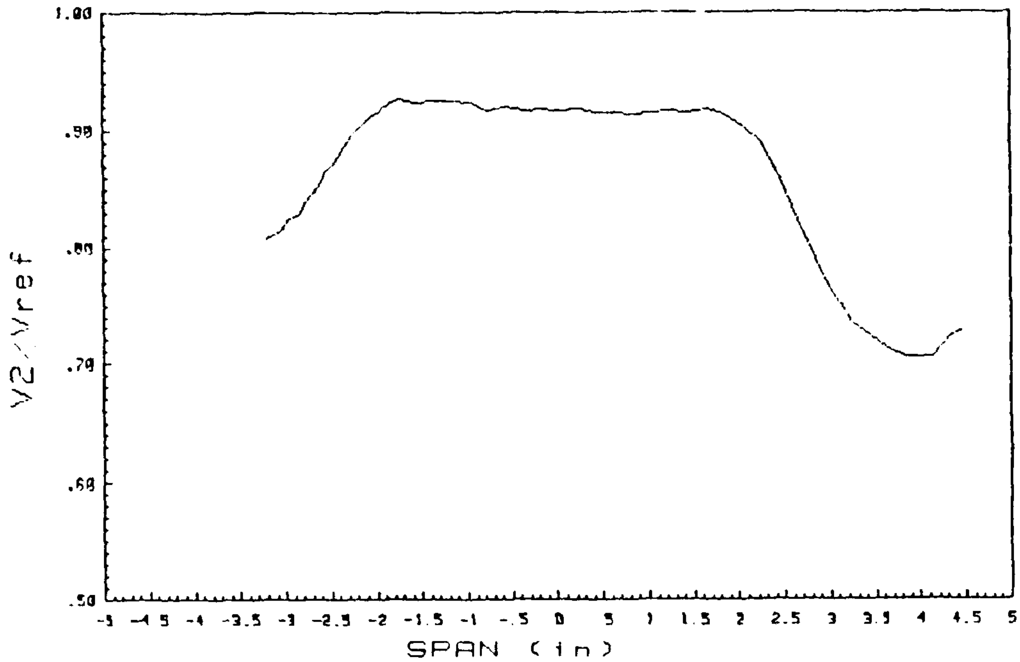


Figure 21a. Reference Blade Downstream Survey: V2/Vref vs. Probe Displacement, Span-wise, Pressure Side

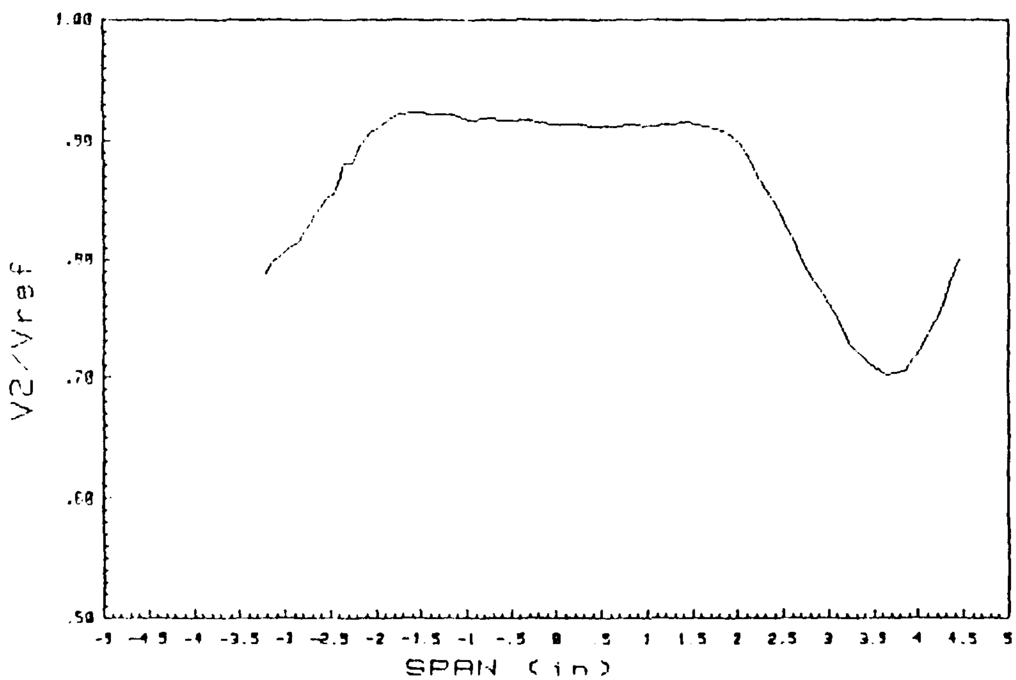


Figure 21b. Slotted Blade Downstream Survey: V2/Vref vs. Probe Displacement, Span-wise, Pressure Side

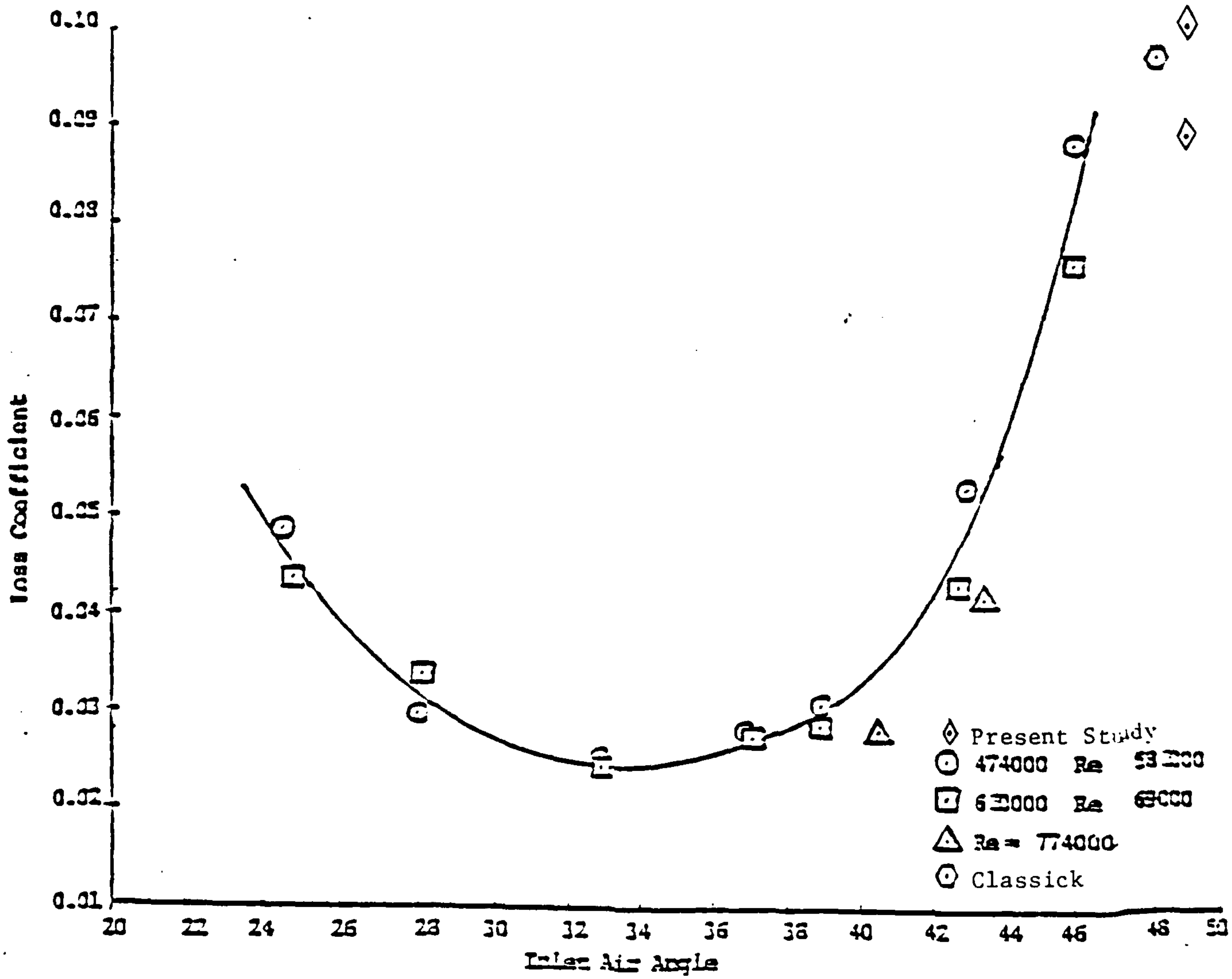


Figure 22. Loss Coefficient vs. Air Inlet Angle

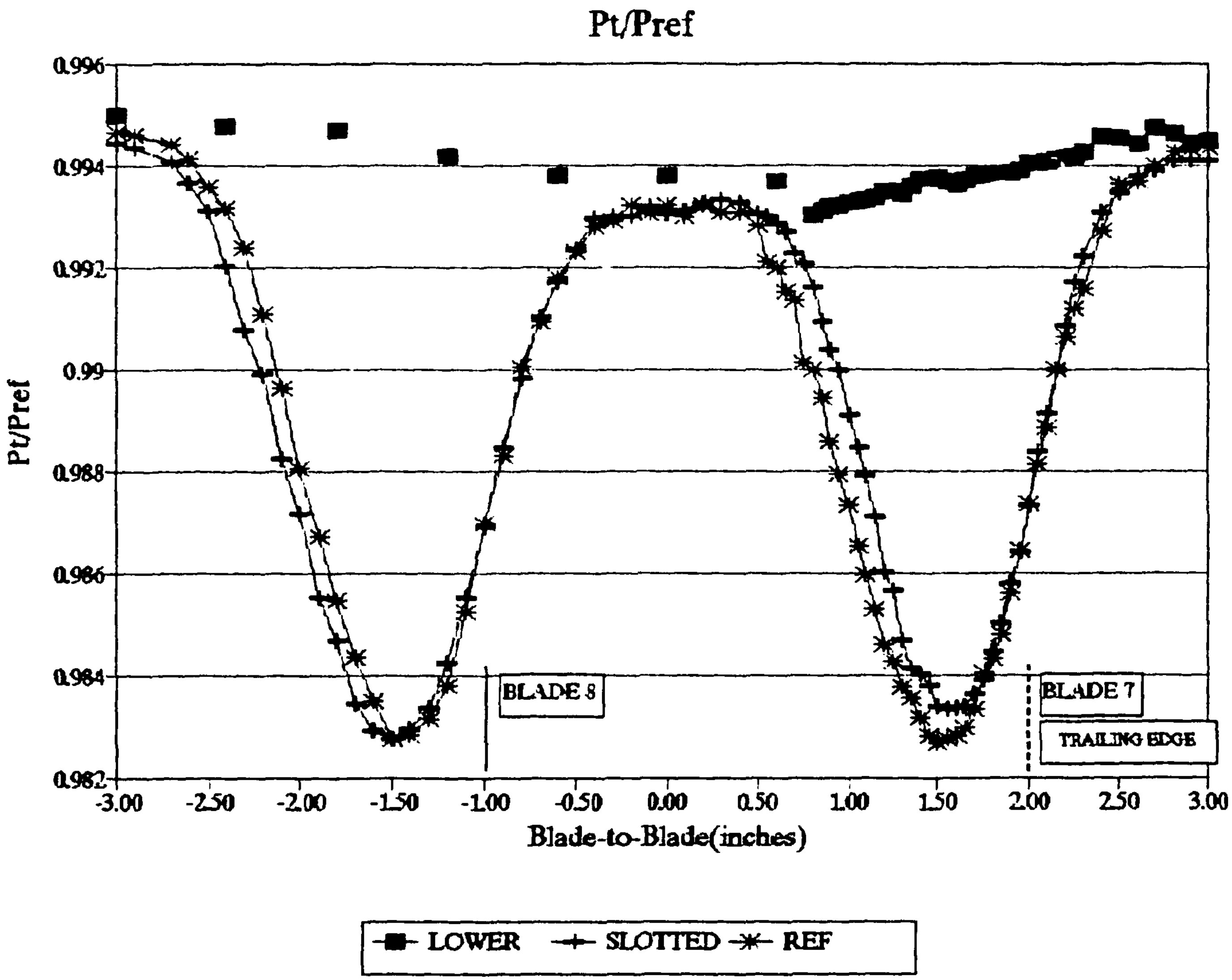


Figure 23. Pt/Pref for Upstream and Downstream Surveys

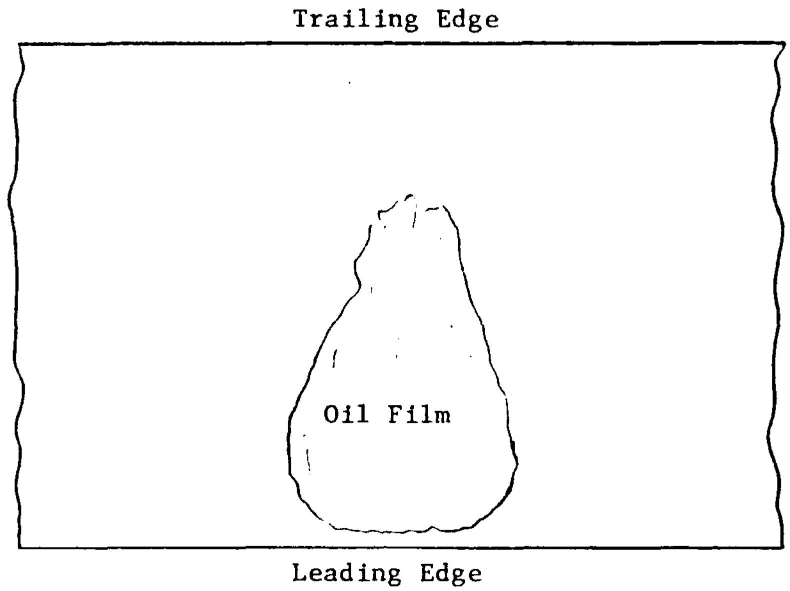


Figure 24a. Reference Blade Leading Edge Flow Visualization

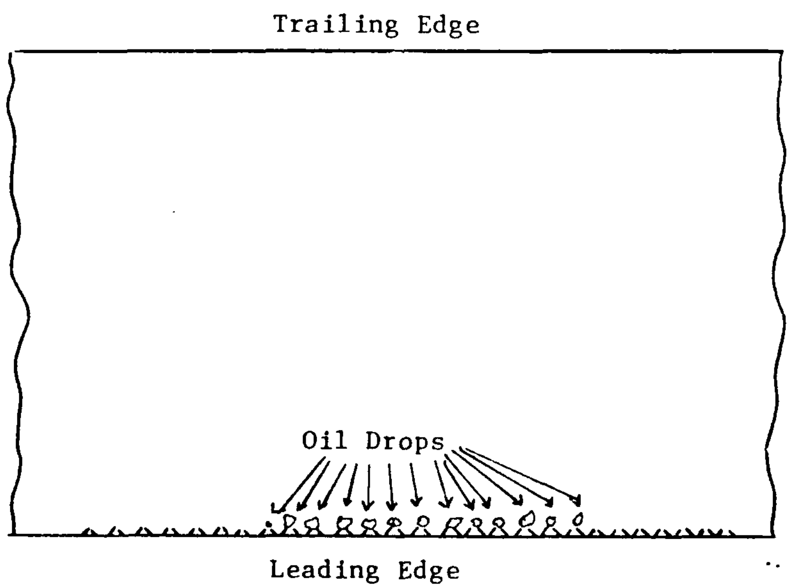


Figure 24b. Slotted Blade Leading Edge Flow Visualization

the span-wise direction shown in Figure 11 were considered to be acceptably uniform in the mid-span region of interest.

2. <u>Two-Dimensionality and Periodicity</u>

Downstream span-wise surveys show a much diminished core of two-dimensional flow on the suction side of the blade (Figures 16a to 18a). This was the result of side-wall and corner flow boundary layer build-up through the test section. The pressure side had a greater core. However, the side-wall effects again were evident (Figures 19a to 21a).

Figures 13a to 15a show good periodicity for the blade passages enclosing blades seven and eight. The first and last points are in good agreement and the spans match in depth, width and shape. Similar periodicity can also be seen in Figure 12 where the values of the coefficient of pressure for the partially instrumented blade are shown plotted with the coefficients for the fully instrumented blade ten.

3. <u>Downstream Flow Field for the Reference Cascade</u>

The reference blade downstream flow field is seen to be qualitatively similar to that found in Dreon's [Ref. 3], Elazar's [Ref. 4] and Classick's [Ref. 6] work. The angle, pressure and velocity profiles across blades seven and eight were very similar (Figures 13a to 15a) to each other. The velocity and pressure in the core regions of the three adjacent passages do not completely agree, as is apparent in Figures 14a and 15a. This is most likely attributable to inlet guide vane variations. The two outside passages (the

endpoints) do agree well however. The span-wise flow profile shows the boundary layer effects on the suction and pressure sides (Figures 16a to 21a) with the suction side indicating a vanishing core as discussed in Section A.2. The measurements of blade performance are considered to be valid but marginal due to the diminishing core.

4. Downstream Flow Field with Slotted Blade

The measurements behind the slotted blade show qualitatively similar profiles to those behind the reference blade. The slots had a measurable effect on the total flow as shown in Figures 14b and 15b. There was a significant effect on the wake of the slotted blade wake but, surprisingly, an equally significant effect on the wake of the adjacent blade. Figures 16b to 18b show that the core effectively vanished on the suction side of the slotted blade. The slots appeared to have a negative influence on the corner effects, which made the integrated results at midspan less certain.

B. REFERENCE AND SLOTTED BLADE PERFORMANCE

Table 4 lists the loss coefficient, axial velocity density ratio (AVDR) and static pressure rise for the mass-averaged and mixed-out flow cases for the reference and slotted blades. The values are also plotted on Figure 22 with results of previous measurements of the reference CD blading at various incidence angles. The calculated mass-averaged loss for the reference blade with accurately referenced yaw angle fits

TABLE 4

REFERENCE AND SLOTTED BLADE SURVEY RESULTS

REFERENCE BLADE

	LOSS	AVDR	CP STATIC
MASS	0.1014	1.016	0.3851
MIXED	0.8760	1.015	

SLOTTED BLADE

	LOSS	AVDR	CP STATIC
MASS	0.08969	1.031	0.3859
MIXED	0.9627	1.031	

well with the earlier work. The calculated mass-averaged loss for the slotted blade shows a noticeable decrease compared to that of the reference blade. The loss reduction is clearly evident in the decreased wake size seen in Figure 23. Figure 23 shows the distribution of losses through the blade wakes by overlapping inlet and exit flow stagnation pressure distributions.

The mixed-out flow losses provide a conflicting result. The calculated values were found to be unrealistic and exhibited completely opposite trends compared to mass-averaged loss. The mass-averaged calculations is such that the supply condition fluctuations are removed by referencing to plenum conditions. As presently carried out the mixed-out flow method does not appear to be sensitive to, even minor tunnel changes. Specifically the ensemble averages of X_{ref} and P_{ref} during inlet and exit surveys are involved in the calculation

of the mixed-out conditions and the losses derived from them. Therefore small changes in the ensemble averages have a very large effect on the calculated losses.

Hence, until a method of referencing is devised which leaves the mixed out loss independent of tunnel operating level, the mass-averaged loss will be accepted as a means for comparing performance.

C. EFFECT OF SLOTTED LEADING EDGE ON FLOW STRUCTURE

Visual observations of the flow over the reference and slotted blades using an atomized oil mist and a LDV laser beam illumination indicated that there was a significant change in the flow between the two types of blades. The pressure side of the reference blade and slotted blade showed identical flow patterns as would be expected since the leading edge slots were positioned such as to have an effect on the separation bubble on the suction side. The reference blade suction side showed a pattern with some oil build up on the leading edge, a dry region of about .25 inches in the region of the separation bubble and the another oil buildup region where the flow reattached to the blade. The oil deposit was concentrated in the center of the blade due to the atomizer positioning and boundary layer of the tunnel. This is illustrated in Figure 24a.

The slotted blade suction side showed a buildup of very small bubbles of oil near the exits of individual slots (where

the oil flow had been channeled through the slots and deposited in the local separations created by the jets). The rest of the blade remained dry as shown in Figure 24b. It appeared that the freestream flow with oil droplets never reattached to the blade after separation. It was not possible to determine changes in separation bubble size with this type of visualization.

V. CONCLUSIONS AND RECOMMENDATIONS

A. LOSS CALCULATIONS

Investigations were conducted at a fixed inlet flow angle of 48.5 degrees of a reference-controlled diffusion compressor cascade and of the same cascade containing one blade with a slotted leading edge. The following conclusions were drawn:

1. At this high angle of incidence, there was a vanishing core of two-dimensional flow at the downstream survey station.
2. The blade element performance quantities derived from the probe measurements were consistent with previous results at lower angle settings.
3. Mass-averaged loss calculations provided consistent and certain results, due to removal of effects of variations in supply conditions inherent in the method.
4. Mixed-out loss calculations, as currently performed, are not useful since the results are sensitive to tunnel supply variations.

The following recommendations for loss measurements are made:

1. Reformulate the mixed-out flow loss calculations to remove the ensemble average values from the calculations.
2. Make probe surveys closer to the blade trailing edge to reduce the effects of side-wall boundary layer buildup on the two-dimensional core of the flow.
3. Automate the probe traverse process and incorporate the use of highly accurate linear variable displacement transducers.
4. Use two probes for simultaneous measurements at upstream and downstream positions by incorporating item 3 and using the capabilities of the current software.

5. Conduct contour mapping of the downstream flow field to better establish flow conditions and quality.

6. Employ the cascade's boundary layer suction provision to extend the two-dimensional core.

7. Conduct probe surveys in the upstream and downstream positions over three blade passages to better establish blade wake effects and verify the accuracy of the losses.

B. SLOTTED BLADE

While the results for the slotted blade must be considered to be exploratory, the following conclusions were drawn:

1. The presence of the slots reduced the losses from the blade.

2. The flow over the suction surface of the blade was significantly changed by the presence of the slots.

It is therefore recommended that more definitive measurements be made to define the effects on the separation bubble, and evaluate the practicality of this form of passive flow control.

APPENDIX A

SLOTTED BLADE DEVELOPMENT

The arrangement of skewed slots at the leading edge of the blade, shown in Figure 4, was intended to generate a series of small jets, pumped by the high pressure near the stagnation point to the very low pressure near the suction peak. This attempted to adapt the ideas outlined by Johnston [Ref. 11] to reduce the size of the leading edge separation bubble by introducing streamwise vortices created when the jets interact with the main flow.

Introduction of the counter-rotating streamwise vortices at the leading edge of the blade, prior to the separation bubble, might cause the flow on the suction surface to remain attached longer but would be expected to create a smaller separation bubble by forcing earlier reattachment. This in turn would decrease the losses across the blade, particularly at high incidence where the bubble was largest. The stagnation point was required to be sufficiently forward of the vortex generator slots that flow through the slots in the suction surface direction was ensured at all angles of incidence. These restrictions governed the details of the placement of the vortex generators at the leading edge.

Uniformity of the generators for the entire span was required. The CD blading studied here was a compressor stator

section which, in practice, would allow slotting without introducing unacceptable stress concentrations. Since slotting of the blades was easier to implement with control of tolerances and uniformity, slotting was chosen rather than attaching solid generators of any type. In particular the small size required was more easily obtained by slotting. Notching of blades in the production of smaller blades could be done using laser techniques.

The stagnation point at the leading edge was determined using the blade surface pressure distributions obtained at 48.52°. The vortex generators were placed so that they were normal to the camber line of the leading edge. This placed the stagnation point forward of the generators and allowed sufficient space for forward movement of the stagnation point at lower incidence angles.

Slot depth and width were determined by the leading edge radius. The leading edge radius was 0.045 inches which allowed only a limited depth in order not to significantly alter the leading edge flow field. A maximum depth of 0.010 inches was chosen for the slots. The leading edge radius also limited the slot length when combined with the chosen depth. In order for the generator to form a jet, its length had to be greater than its width. At the slot angle of 52° and a maximum depth of 0.010 inches a slot width of 0.010 provided a length-to-width ratio of approximately three. This was

sufficient to create a defined jet and yet allow for stagnation point movement at lower incidence angles.

A slot angle of 45° was chosen initially. However, due to machinery limitations, an angle of 52° was used. Spacing between leading and trailing edges of the slots was arbitrarily chosen as 0.020 inches. This allowed 67 slot pairs to be placed on the leading edge of the ten inch span of the CD blading. Figure 4 illustrates the slotted leading edge at a 10X scale.

The slots were made using a 0.010 inch-wide by 2.5 inch-diameter Jewelers Slotting Blade with 90 teeth. The shape of the blade limited the slots to rectangular or square cuts with the size depending only on depth of cut and chosen blade width. The slotting blade was mounted in a milling machine with digital precision position indicators. The milling head size and CD blade span limited the angle of the leading edge slots to 52.2°. The slots were made in one direction first, then the cascade blade was reversed and the second set of cuts was made. Slot widths of 0.010 inches to a tolerance of .0005 inch was determined by the blade. Slot depth was checked every inch of span and a tolerance of 0.001 was maintained. Slot trailing edge spacing was also checked visually every inch and a tolerance of 0.005 inches was maintained. The angle tolerance was fixed in each direction. In view of the need to reverse the work under the machining head the consistency in angle could only be maintained to 0.4°.

Figure A1 shows the CD leading edge slots in the midspan region. This view is from the suction (upper) surface of the blade. Figure A2 shows the same slots from the frontal aspect.

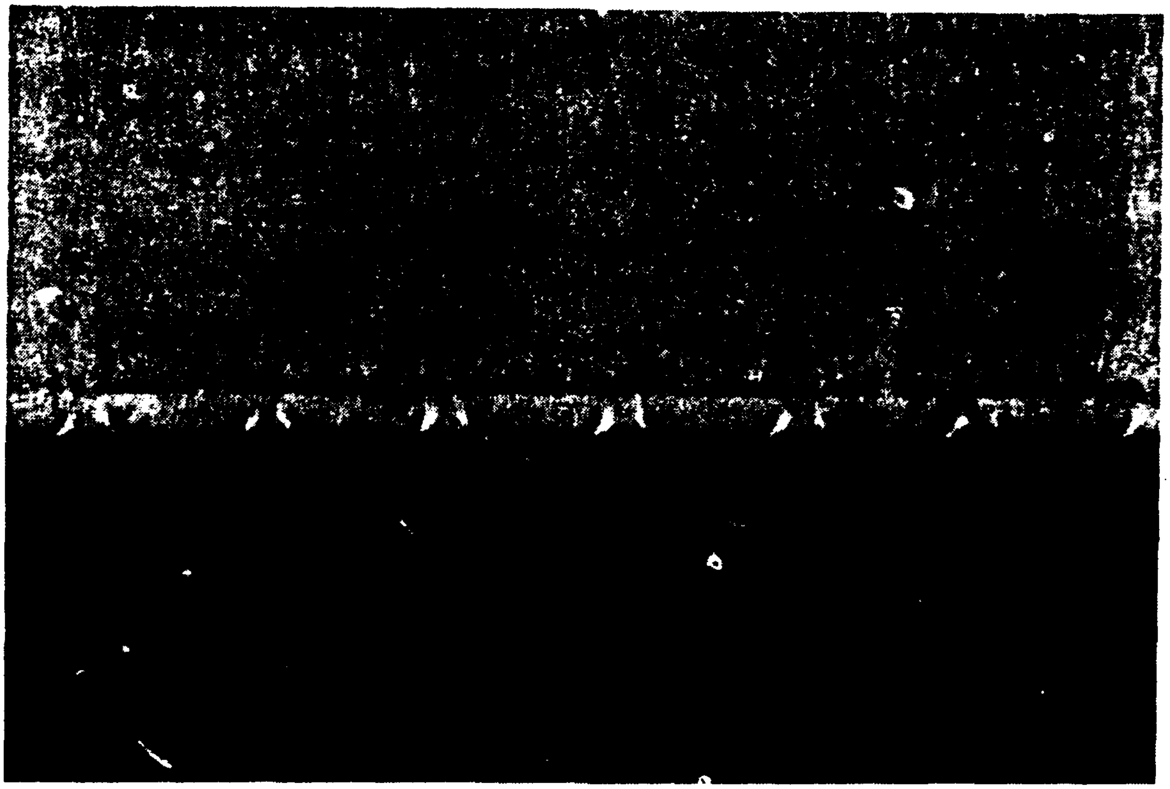


Figure A1. Slotted Blade Leading Edge, Suction Surface View

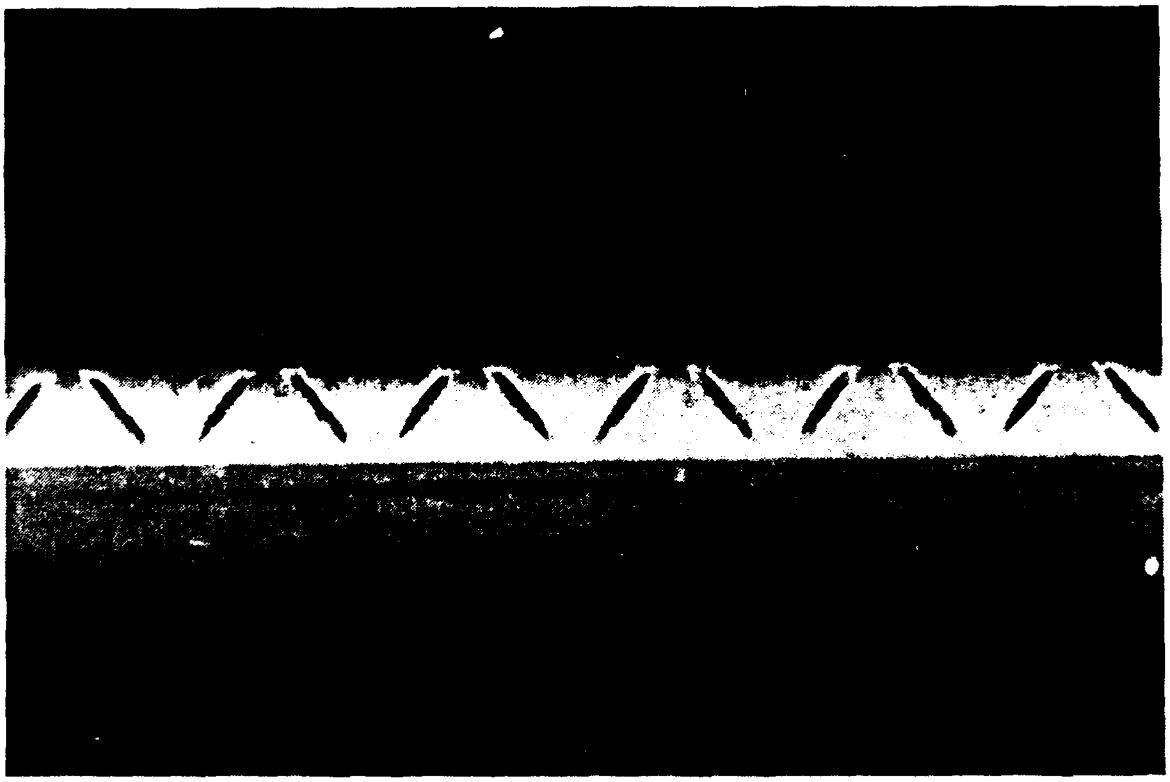


Figure A2. Slotted Blade Leading Edge, Frontal View

APPENDIX B

SOFTWARE

B1. INTRODUCTION

The software used for data acquisition and reduction consists of three programs--"ACQUIRE," "CALC" and "LOSS," as developed and discussed by Classick [Ref. 6]. The intent in the present work was to introduce necessary program changes without changing the original program flow. Therefore Appendix C of Reference 6 should still be used for file system, program flow and program executions. "CALC" and "LOSS" were modified to provide Reynolds number calculations, probe angle referencing and fully-mixed-out loss calculation and these changes are discussed in the present section.

The file system is given in Section B2. The modified program flow for "LOSS" is given in Section B3. The changes to "CALC" and "LOSS" are discussed in Section B4. Copies of the three programs and associated subroutines are included in Section B5. Output data tables of reduced data for upstream and downstream surveys of both the reference and slotted blade are illustrated in Section B6. Recommendations for software improvements are given in Section B7. Lastly a summary of steps required for running the three programs is provided in Section B8.

B2. FILE SYSTEM

The current directory and file system is shown in Figure B1. Four subdirectories exist under the Root directory "CLASSICK." The "DATA" subdirectory contains the raw data files created during the data acquisition. The "REDDATA" subdirectory contains the scaled data files from the acquisition and the reduced data files from the "CALC" program. The "PROGS" subdirectory contains the acquisition programs, data reduction programs and data plotting programs. The "ROUTINES" subdirectory contains the sub-routines utilized by three programs in the "PROGS" subdirectory.

The data file names are descriptive in nature. The prefix (L, U, SUP, SUS, B) designates the survey type. The number followed by three characters provide the date (26AUG, 4SEP) and the suffix (RAW, SCL, CALC) give the file type. If more than one run was conducted on the same day a number is added to the suffix (RAW1, SCL1). To designate the blade surveyed, a blade number is embedded in the file type (L-04MAY7RAW). To designate the modified blade the character "M" was embedded (L-04MAYMRAW).

B3. PROGRAM FLOW

The program flow for "ACQUIRE" and "CALC" remain unchanged from Classick [Ref. 6]. Figure B2 shows the flow for the program "LOSS." The figure shows the prompts the user will have on the screen and the effect that the selected

CLASSICK

Root Directory

Sub Directory

DATA	REDDATA	PROGS	ROUTINES
S-07APR7RAW	S-07APR7SCL	ACQUITE	SUBACQUIRE
L-04MAY7RAW	L-04MAY7SCL	CALC	SUBCALC
U-22MAY7RAW	U-22MAY7SCL	LOSS	LOSSCALC
U-01JUNRAW	U-01JUNSCL	PRBCOEF	SUBMIXLOSS
U-31MAYMRAW	U-31MAYMSCL	CYBLADEPLOT	
SUS-25APR7RAW	SUS-25APR7SCL	VUREFSPAN	
SUP-24APR7RAW	SUP-24APR7SCL	BETAPOSIT	
SUS-23MAYMRAW	SUS-23MAYMSCL	PRESSPLOT	
SUP-24MAYMRAW	SUP-24MAYMSCL		
L-29MARTRAW	L-29MARTSCL		
B-22MAYMRAW	B-22MAYMSCL		
	S-07APR7CALC		
	L-04MAY7CALC		
	U-22MAY7CALC		
	U-01JUNCALC		
	U-31MAYMCALC		
	SUS-25APR7CALC		
	SUP-24APR7CALC		
	SUS-23MAYMCALC		
	SUP-24MAYMCALC		
	L-29MARTCALC		
	B-22MAYMCALL		
	MIKEC3		
	MIKECE		

Prefix

L	Lower Traverse
U	Upper Traverse
S	Span Lower Traverse
SUP	Span Upper Traverse Pressure
SUS	Span Upper Traverse Suction
B	Blade

Suffix

RAW	Raw Voltage Reachings
SCL	Engineering Scaled
CALC	Reduced

Figure B1. Directory and File Listing

B

↓

PROGRAM LOSS

↓

Enter name of the file containing the calculated data from the lower probe

↓

Enter the high scan number for the lower probe

↓

Enter the name of the file containing the calculated data from the upper probe

↓

Enter the high scan number for the upper probe file

↓

Enter the limit of integration for the lower probe survey

↓

Enter the lower scan limit

↓

Enter the upper scan limit

↓

Enter the limit of integration for the upper probe survey

↓

Enter lower scan limit

↓

Enter upper scan limit

↓

Loss printout printed to the printer

↓

END PROGRAM

Figure B2. Program "LOSS" Flow

option has. The changes to previous work were those required to provide an angle input for referencing the probe pneumatic axis, scan lengths to decrease file size and execution time, and integration intervals to provide for fully-mixed-out losses.

B4. PROGRAM MODIFICATIONS

1. Program "CALC"

The "CALC" program for data reduction was modified to include the calculation of the Reynolds number of the flow, correct for probe angle referencing and to provide required parameters for fully-mixed-out loss calculations in the program "LOSS."

The Reynolds number calculation required the addition of subroutines "Murefensemble" for finding the average coefficient of viscosity discussed in Appendix C, and "Datint" to find the integral "Iintg" for the value of Eqn. C8. These changes are shown in line 2507 and line 2529 of Table B1 respectively. Prompts were required to ask for the integration interval to be used based on scan number. The interval should span three inches or less to work with the "Datint" integration subroutine.

The probe angle referencing correction required a prompt for the input of angle β_H as discussed in Appendix F, and the subsequent equation for calculating the angle β in the

TABLE B1

CALC PROGRAM LISTING

```
10   !PROGRAM CALCS    ! THIS PROGRAM TAKES THE FILES OF DATA COLLECTED FROM TH
20   ! AND REDUCES THE DATA TO  USEFUL ENGINEERING QUANTITIES THESE
25   ! VALUES ARE PRINTED IN TABLE FORM.
30   !MUCH OF THE CODING IN THIS PROGRAM HAS BEEN PREVIOUSLY COMMENTED ON
35   !IN PROGRAM ACQUIRE.
40   OPTION BASE 1
45   DIM Reddat(1,106)             !AN ARRAY FOR THE SCALED DATA FROM ACQUIRE.
50                                 !RECALL THAT THE SCALED DATA WAS STORED BY
55                                 !A RANDOM OUTPUT STATEMENT.
60   DIM P(6,6)                    !THE ARRAY FOR THE PHI COEFFICIENTS.
65   DIM X(6,6)                    !THE ARRAY FOR THE X VELOCITY COEFFICIENTS.
70   DIM Pu(6,6)                   !IF 2 PROBES USED THEN THE PHI ARRAY FOR
75                                 !THE UPPER PROBE.
80   DIM Xu(6,6)
85   DIM Knaray(100)               !KN VALUES STORED IN AN ARRAY.Kn=K IN TABLE
90                                 !I OF CLASSICK THESIS.
95   DIM Prbpos(100)
100  DIM Aaray(100)                !AN ARRAY OF VALUES USED IN THE CALCULATION
105  DIM Baray(100)                !OF BLADE CP'S.
110  DIM Caray(100)
115  MAT Reddat= (0)
120  MAT Knaray= (0)
125  MAT Prbpos= (0)
130  MAT Aaray= (0)
135  MAT Baray= (0)
140  MAT Caray= (0)
145  DEG                           !ALL ANGLES WILL BE IN DEGREES.
150  Prnter=701
155  Scren=1
160  Firstbladeprt=4               !FIRST SCANIVALVE PORT ASSIGNED TO THE
165                                !INSTRUMENTED BLADE THAT IS OF INTEREST
170                                !IN THE CP CALCULATION.
175  Lastbladeprt=48               !LAST " " "act.
180  G=1.4
185  Cp=.24
190  LOADSUB ALL FROM "/CLASSICK/ROUTINES/SUBCALC"
195  MASS STORAGE IS "/CLASSICK/REDDATA"
200  PRINT "*****************************************************************"
205  PRINT ""
210  PRINT "ENTER THE NAME OF THE FILE CONTAINING THE PROBE DATA SCALED"
215  PRINT "TO ENGINEERING UNITS"
220  INPUT Sclfile$
225  ASSIGN @Path1 TO Sclfile$
230  PRINT "*****************************************************************"
235  PRINT ""
240  PRINT "ENTER THE PROBE COEFFICIENT FILE FOR X VELOCITY. THIS WILL BE "
245  PRINT ""
250  PRINT "FOR THE LOWER PROBE IF TWO PROBES ARE BEING USED."
255  INPUT Readx$
260  ASSIGN @Path2 TO Readx$
265  ENTER @Path2;X(*)
270  PRINT "*****************************************************************"
275  PRINT ""
280  PRINT "ENTER THE NAME OF THE COEFFICIENT FILE FOR PHI. THIS WILL BE "
285  PRINT ""
290  PRINT "FOR THE LOWER PROBE IF TWO PROBES ARE BEING USED."
295  INPUT Readp$
300  ASSIGN @Path3 TO Readp$
305  ENTER @Path3;P(*)
310  PRINT "*****************************************************************"
315  PRINT ""
320  PRINT "IF DATA WERE COLLECTED WITH ONE PROBE, PRESS "" ONE PROBE"""
325  PRINT ""
330  PRINT "IF DATA WERE COLLECTED WITH TWO PROBES, PRESS ""TWO PROBES"""
```

```
335   PRINT ""
340   PRINT "****************************************************************"
345   ON KEY 1 LABEL "ONE      PROBE" GOTO Numberprbs1
350   ON KEY 4 LABEL "TWO      PROBES" GOTO Numberprbs2
355 Spin1:   GOTO Spin1
360 Numberprbs1:    Noofprbs=1
365   GOTO Checknoofprbs
370 Numberprbs2:    Noofprbs=2
375 Checknoofprbs:  IF Noofprbs=2 THEN
380   MASS STORAGE IS "/CLASSICK/REDDATA"
385   PRINT "****************************************************************"
390   PRINT ""
395   PRINT "ENTER THE FILE NAME FOR THE UPPER PROBE COEFFICIENTS FOR Xvel."
400   INPUT Readxu$
405   ASSIGN @Path2u TO Readxu$
410   ENTER @Path2u;Xu(*)
415   PRINT "****************************************************************"
420   PRINT ""
425   PRINT "ENTER THE FILE NAME FOR THE UPPER PROBE COEFFICIENTS FOR PHI."
430   INPUT Readpu$
435   ASSIGN @Path3u TO Readpu$
440   ENTER @Path3u;Pu(*)
445   PRINT "****************************************************************"
450   PRINT ""
455   PRINT "ENTER THE FILENAME FOR THE DATA TO BE CALCULATED FROM LOWER PROBE "
460   INPUT Calclfile$
465   CREATE BDAT Calclfile$,100
470   ASSIGN @Path4 TO Calclfile$
475   PRINT "****************************************************************"
480   PRINT ""
485   PRINT "ENTER THE FILENAME FOR THE DATA TO BE CALCULATED  FROM UPPER PROBE"
490   INPUT Calcufile$
495   CREATE BDAT Calcufile$,100
500   ASSIGN @Path5 TO Calcufile$
505   !****************************************************************
510   !*      NOTE: THE SCANIVALVE SENSES THE PRESSURE DIFFERENTIAL FROM      *
515   !*            ATMOS. THE SCANIVALVE IS CALIBRATED SO ATMOS PRESS(Pa)    *
520   !*            READS ZERO. THE PRESS SENSED AT A PORT IS THE PORT        *
525   !*            PRESS MINUS Pa i.e.,GAGE PRESS. TO ELIMINATE ERRORS DUE   *
530   !*            TO DVM DRIFT, THE  PRESS SENSED BY PORT 1 OF THE          *
535   !*            SCANIVALVE (Ptare=Pa-Pa) IS SUBTRACTED FROM EACH          *
540   !*            SCANIVALVE PORT READING.                                  *
545   !*                                                                      *
550   !********************* TWO PROBES ***********************************
555   !**********SCANIVALVE PORT AND SCANNER CHANNEL ASSIGNMENT**************
560   !*                                                                      *
565   !*                                                                      *
570   !*  VARIABLE    VARIABLE             PORT/CHANNEL    DATA ARRAY         *
575   !*              REPRESENTS                                              *
580   !*                                                                      *
585   !*  Ptare       Pa-Pa                PORT 1          Reddat(1,1)        *
590   !*  Pcal        Pcal-Ptare           PORT 2          Reddat(1,2)        *
595   !*  Pp          Pplenum-Ptare        PORT 3          Reddat(1,3)        *
600   !*  Ps          Pwallstatic-Ptare    PORT 4          Reddat(1,4)        *
605   !*  P1          P1-Ptare             PORT 5          Reddat(1,5)        *
610   !*  P2          P2-Ptare             PORT 6          Reddat(1,6)        *
615   !*  P3          P3-Ptare             PORT 7          Reddat(1,7)        *
620   !*  P23         (P2+P3)/2                                               *
625   !*  P4          P4-Ptare             PORT 8          Reddat(1,8)        *
630   !*  P5          P5-Ptare             PORT 9          Reddat(1,9)        *
635   !*  Ptp       Ptotalprndtl-Ptare     PORT 10         Reddat(1,10)       *
640   !*  Psp       Pstatprndtl-Ptare      PORT 11         Reddat(1,11)       *
645   !*              BLANK                PORT 12         Reddat(1,12)       *
650   !*  Plu         Plu-Ptare            PORT 13         Reddat(1,13)       *
```

```
660  !*  P3u       P3u-Ptare            PORT 15       Reddat(1,15)        *
665  !*  P23u      (P2u+P3u)/2                                             *
670  !*  P4u       P4u-Ptare            PORT 16       Reddat(1,16)        *
675  !*  P5u       P5u-Ptare            PORT 17       Reddat(1,17)        *
680  !*             BLANK               PORT 18       Reddat(1,18)        *
685  !*             BLANK               PORT 19       Reddat(1,19)        *
690  !*  Posit     L PRB POSIT          INPUT         Reddat(1,20)        *
695  !*  Positu    U PRB POSIT          INPUT         Reddat(1,21)        *
700  !*  Yaw       LOWER PRB YAW        24            Reddat(1,22)        *
705  !*  Yawu      UPPER PRB YAW        21            Reddat(1,23)        *
710  !*  Temp      TOTAL TEMP(PLENUM)   CHAN 10       Reddat(1,24)        *
715  !*  Pa        ATMOSPHERIC PRESS    INPUT         Reddat(1,25)        *
720  !*                                                                    *
725  !*                                                                    *
730  !********************************************************************
735  !*******************DATA REDUCTION***********************************
740  DIM Calcl(100,25)
745  MAT Calcl= (0)
750  Pinitiall=0                        !INITIALIZES THE CONDITIONS TO CALCULATE
755                                     !ENSEMBLE VALUES IN SUBROUTINE ENSEMBLE
760  Tinitial=0
765  Painitiall=0
770  FOR N=1 TO 100
775  ENTER @Path1,N;Reddat(*)          !THE ARRAY IS ENTERED WITH A RANDOM
780                                     !STATEMENT.
785  ON END @Path1 GOTO Twoprintcalcl
790  Ptare=Reddat(1,1)                 !REASSIGNMENT OF ARRAY ELEMENTS TO
795                                     !IDENTIFIABLE QUANTITIES TO BE USED IN
800                                     !IN SUBROUTINE CALCULATIONS.
805  Pcal=Reddat(1,2)
810  Pp=Reddat(1,3)
815  Ps=Reddat(1,4)
820  P1=Reddat(1,5)
825  P2=Reddat(1,6)
830  P3=Reddat(1,7)
835  P23=(P2+P3)/2
840  P4=Reddat(1,8)
845  P5=Reddat(1,9)
850  Ptp=Reddat(1,10)
855  Psp=Reddat(1,11)
860  !BLANK=Reddat(1,12)
865  Posit=Reddat(1,20)
870  Yaw=Reddat(1,22)                       !YAW ANGLE CORRECTION COULD BE MADE
875                                         !HERE IF NOT ALREADY DONE IN ACQUIRE.
880  Temp=Reddat(1,24)
885  Pa=Reddat(1,25)
890  !CALCULATE BETA AND GAMMA COEFFICIENTS
895  CALL Bgcalc(Pa,P1,P23,P4,P5,Beta,Gamma)
900  !CALCULATE THE ENSEMBLE REFERENCE VALUES OF PLENUM PRESS,PLENUM TEMP AND PA
905  CALL Ensemble(Pp,Pinitial,Pa,Painitial,Temp,Tinitial,Ppavg,Paavg,Tempavg,N)
910  !CALCULATE Xvel AND Phi
915  CALL Xphicalc(Beta,Gamma,Xvel,X(*),Phi,P(*))
920  !CALCULATE Xref
925  CALL Xrefcalc(Pa,Pp,G,Xref)
930  !CALCULATE QREF AND VREF
935  CALL Qvrefcalc(Xref,Cp,Temp,G,Pp,Pa,Qref,Vref)
940  !CALCULATE VELOCITY AND MACH # AND Q
945  CALL Vmqcalc(Xvel,Cp,Temp,G,Vel,Mach,P1,Pa,Q)
950  ! CALCULATE THE INTEGRAND FOR THE AVDR EXPRESSION
955  CALL Kncalc(Pa,P1,Pp,Xvel,Xref,G,Yaw,Kn)
960  !CALCULATE THE COEFFICIENT OF PRESSURE TERM TO BE MASS AVERAGED.
965  !THESE TERMS ARE USED IN THE CALCULATION OF THE LOSS COEFFICIENT.
970  CALL Coefpress(P1,Pp,Pa,Xvel,G,Cps,Cpt)
975  !CALCULATE THE  QUANTITIES TO BE MASS AVERAGED  MULTIPLY THESE VALUES
```

TABLE B1 (CONTINUED)

```
980  !BY Kn TO GET THE INTEGRAND REQUIRED TO CALCULATE THE MASS AVERAGED CP'S
985  CALL Cpintegrand(Pp,P1,Pa,G,Xvel,A,B,Kn)
990  ! CALCULATE Pp-P1/Qref FOR PLOTS
995  CALL Prefqref(Pp,P1,Qref,Pq)
1000 ! CALCULATE STATIC PRESSURE UPSTREAM
1005 CALL Staticpress(P1,Pa,Xvel,G,Ps)
1010 !DEFINE AN ARRAY TO STORE CALCULATED VALUES
1015 Calcl(N,1)=Posit
1020 Calcl(N,2)=Beta
1025 Calcl(N,3)=Gamma
1030 Calcl(N,4)=Phi
1035 Calcl(N,5)=Xvel
1040 Calcl(N,6)=Xref
1045 Calcl(N,7)=Vel
1050 Calcl(N,8)=Mach
1055 Calcl(N,9)=Yaw
1060 Calcl(N,10)=Kn
1065 Calcl(N,11)=Cpt
1070 Calcl(N,12)=Cps
1075 Calcl(N,13)=Qref
1080 Calcl(N,14)=Vref
1085 Calcl(N,15)=Q
1090 Calcl(N,16)=A
1095 Calcl(N,17)=B
1100 Calcl(N,18)=Pq
1105 Calcl(N,19)=Pa                     !Pa & Ps ARE USED FOR STATIC PRESS
1110                                    !RISE CALCULATION IN PROGRAM LOSS.
1115 Calcl(N,20)=Ps                     !THESE VALUES ARE NOT PRINTED.
1120 Knaray(N)=Calcl(N,10)              !WANT TO STORE MORE THAN JUST ONE
1125                                    !Kn VALUE FOR MASS AVERAGING
1130                                    !CALCULATIONS.
1135 Prbpos(N)=Calcl(N,1)               !"" ""
1140 Aaray(N)=Calcl(N,16)               !"" ""
1145 Barny(N)=Calcl(N,17)               !"" ""
1150 Scan=N
1155 NEXT N
1160 Twoprintcalcl: OFF END @Path1
1165 !CALCULATE ENSEMBLE AVERAGE OF XREF
1170 CALL Xrefensemble(Paavg,Ppavg,G,Xrefavg)
1175 !CALCULATE ENSEMBLE AVERAGE OF VREF
1180 CALL Vrefensemble(Xrefavg,Cp,Tempavg,Vrefavg)
1185 !CALCULATE ENSEMBLE AVERAGE OF QREF
1190 CALL Qrefensemble(Paavg,Ppavg,G,Xrefavg,Qrefavg)
1195 PRINT "************************************************************"
1200 PRINT ""
1205 PRINT "ALIGN PAPER IN PRINTER. WHEN READY FOR A HARDCOPY OF THE "
1210 PRINT "CALCULATED DATA, PRESS ""REDUCED DATA""."
1215 PRINT ""
1220 PRINT "************************************************************"
1225 ON KEY 1 LABEL "REDUCED DATA" GOTO Prntdata2
1230 Spin2: GOTO Spin2
1235 Prntdata2: PRINTER IS Prnter
1240 PRINT "*******************************"
1245 PRINT "FILE ",Calclfile$
1250 PRINT "*******************************"
1255 PRINT "**************************************************************
1260 PRINT ""
1265 PRINT "SCAN   L PRB     BETA          GAMMA         PHI           Xvel
1270 PRINT "        POSIT"
1275 FOR N=1 TO Scan
1280 PRINT USING "4D,3X,4D.2D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,2X,MD.3DE,2X,MD.3DE
1285 NEXT N
1290 PRINT ""
1295 PRINT "**************************************************************
```

```
1300  PRINT ""
1305  PRINT "SCAN   VEL          VREF          Q              QREF          MACH
1310  PRINT "
1315  FOR N=1 TO Scan
1320  PRINT USING "4D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,2X,MD.3DE,2X,MD.3D
1325  NEXT N
1330  PRINT ""
1335  PRINT "****************************************************************
1340  PRINT ""
1345  PRINT "****************************************************************
1350  PRINT ""
1355  PRINT "SCAN   Pref-Ptl/Qref"
1360  FOR N=1 TO Scan
1365  PRINT USING "4D,3X,MD.3DE";N,Calc(N,18)
1370  NEXT N
1375  PRINT ""
1380  PRINT "****************************************************************
1385  PRINT ""
1390  PRINT "ENSEMBLE AVERAGES"
1395  PRINT ""
1400  PRINT "PPAVG          PAAVG          TEMPAVG     XREFAVG        VREFAVG
1405  PRINT USING "MD.3DE,5X,M3D.2DE,5X,3D.2D,5X,MD.3DE,5X,MD.3DE,3X,MD.3DE";Ppa
1410  OUTPUT @Path4;Calcl(*)                         !OUTPUT STATEMENT IS SERIAL.
1415  DIM Calcu(100,25)                              !SEPARATE CALC ARRAY FOR REDUCED
1420                                                 !DATA FROM UPPER SURVEY STATION.
1425  MAT Calcu= (0)
1430  FOR N=1 TO 100
1435  ENTER @Path1,N;Reddat(*)                       !ENTER STATEMENT IS RANDOM.
1440  ON END @Path1 GOTO Twoprintcalc2
1445  Ptare=Reddat(1,1)
1450  Pp=Reddat(1,3)
1455  Ps=Reddat(1,4)
1460  Ptp=Reddat(1,10)
1465  Psp=Reddat(1,11)
1470  P1u=Reddat(1,13)
1475  P2u=Reddat(1,14)
1480  P3u=Reddat(1,15)
1485  P2u3u=(P2u+P3u)/2
1490  P4u=Reddat(1,16)
1495  P5u=Reddat(1,17)
1500  !BLANK=REDDAT(1,18)
1505  !BLANK=REDDAT(1,19)
1510  Positu=Reddat(1,21)
1515  Yawu=Reddat(1,23)
1520  Temp=Reddat(1,24)
1525  Pa=Reddat(1,25)
1530  !CALCULATE BETA AND GAMMA COEFFICIENTS
1535  CALL Bgcalc(Pa,P1u,P2u3u,P4u,P5u,Betau,Gammau)
1540  !CALCULATE Xvelu AND Phiu
1545  CALL Xphicalc(Betau,Gammau,Xvelu,Xu(*),Phiu,Pu(*))
1550  !CALCULATE Xrefu
1555  CALL Xrefcalc(Pa,Pp,G,Xrefu)
1560  !CALCULATE QREF AND VREF
1565  CALL Qvrefcalc(Xref,Cp,Temp,G,Pp,Pa,Qref,Vref)
1570  !CALCULATE VELOCITYu AND MACHu # AND Qu
1575  CALL Vmqcalc(Xvelu,Cp,Temp,G,Velu,Machu,P1u,Pa,Qu)
1580  ! CALCULATE THE INTEGRAND FOR THE AVDR EXPRESSION
1585  CALL Kncalc(Pa,P1u,Pp,Xvelu,Xrefu,G,Yawu,Knu)
1590  ! CALCULATE THE COEFFICIENT OF PRESSURE FOR THE UPPER PROBE.
1595  ! THIS TERM WILL BE MASS AVERAGED AND USED IN THE CALCULATION OF THE
1600  ! LOSS COEFFICIENT. THE Cpsu TERM IS NOT USED IN THE LOSS COEFFICIENT
1605  ! CALCULATION.
1610  CALL Coefpress(P1u,Pp,Pa,Xvelu,G,Cpsu,Cptu)
1615  ! CALCULATE Pp-P1/Qref FOR PLOTS
```

```
1620  CALL Prefqref(Pp,P1,Qref,Pnu)
1625  ! CALCULATE THE DOWNSTREAM STATIC PRESSURE
1630  CALL Staticpress(P1u,Pa,Xvelu,G,Psu)
1635  Calcu(N,1)=Positu
1640  Calcu(N,2)=Betau
1645  Calcu(N,3)=Gammau
1650  Calcu(N,4)=Phiu
1655  Calcu(N,5)=Xvelu
1660  Calcu(N,6)=Xrefu
1665  Calcu(N,7)=Velu
1670  Calcu(N,8)=Machu
1675  Calcu(N,9)=Yawu
1680  Calcu(N,10)=Knu
1685  Calcu(N,11)=Cptu
1690  Calcu(N,12)=Cpsu
1695  Calcu(N,13)=Qu
1700  Calcu(N,14)=Pqu
1705  Calcu(N,19)=Pa                    !Calcu(N,15) TO Calcu(N,18) WILL HAVE
1710  Calcu(N,20)=Psu                   !ZEROS. ARRAY ELEMENT ASSIGNMENT IS
1715                                    !CONSISTENT WITH LOSS PROGRAM AND
1720                                    !ONE PROBE SURVEY.
1725  Scan=N
1730  NEXT N
1735 Twoprintcalc2:  OFF END @Path1
1740  PRINT "************************************************************
1745  PRINT ""
1750  PRINT "**********************************"
1755  PRINT "FILE    ",Calcufile$
1760  PRINT "**********************************"
1765  PRINT "************************************************************
1770  PRINT ""
1775  PRINT  SCAN  U PRB     BETAU         GAMMAU        PHIU          Xvelu "
1780  PRINT "        POSIT"
1785  FOR N=1 TO Scan
1790  PRINT USING "4D,2X,4D.2D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE";N,Calcu(
1795  NEXT N
1800  PRINT "************************************************************
1805  PRINT ""
1810  PRINT "SCAN    VELU          QU          Pref-Ptu/Qref    MACHU          YAWU"
1815  PRINT "                                                                DEG"
1820  FOR N=1 TO Scan
1825  PRINT USING "4D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE";N,Calcu
1830  NEXT N
1835  PRINT "************************************************************
1840  PRINTER IS Screen
1845  OUTPUT @Path5;Calcu(*)
1850  ELSE
1855  MASS STORAGE IS "/CLASSICK/REDDATA"
1860  PRINT "************************************************************
1865  PRINT ""
1870  PRINT "ENTER THE FILENAME FOR THE DATA TO BE CALCULATED FROM THE PROBE "
1875  INPUT Calcfile$
1880  CREATE BDAT Calcfile$,100
1885  ASSIGN @Path4 TO Calcfile$
1890  !*************************************************************
1895  !********************* ONE PROBE ******************************
1900  !**********SCANIVALVE PORT AND SCANNER CHANNEL ASSIGNMENT**************
1905  !*                                                                *
1910  !*                                                                *
1915  !*  VARIABLE     VARIABLE            PORT/CHANNEL    DATA ARRAY    *
1920  !*               REPRESENTS                                       *
1925  !*                                                                *
1930  !*  Ptare        Pa-Pa               PORT 1          Reddat(1,1)   *
1935  !*  Pcal         Pcal-Ptare          PORT 2          Reddat(1,2)   *
```

TABLE B1 (CONTINUED)

```
1940  !*  Pp        Pplenum-Ptare        PORT 3          Reddat(1,3)      *
1945  !*  Ps        Pwallstatic-Ptare    PORT 4          Reddat(1,4)      *
1950  !*  P1        P1-Ptare             PORT 5          Reddat(1,5)      *
1955  !*  P2        P2-Ptare             PORT 6          Reddat(1,6)      *
1960  !*  P3        P3-Ptare             PORT 7          Reddat(1,7)      *
1965  !*  P23       (P2+P3)/2                                             *
1970  !*  P4        P4-Ptare             PORT 8          Reddat(1,8)      *
1975  !*  P5        P5-Ptare             PORT 9          Reddat(1,9)      *
1980  !*  Ptp       Ptotalprndtl-Ptare   PORT 10         Reddat(1,10)     *
1985  !*  Psp       Pstatprndtl-Ptare    PORT 11         Reddat(1,11)     *
1990  !*              BLANK              PORT 12         Reddat(1,12)     *
1995  !*              BLANK              PORT 13         Reddat(1,13)     *
2000  !*              BLANK              PORT 14         Reddat(1,14)     *
2005  !*  Posit     PRB POSIT            INPUT           Reddat(1,15)     *
2010  !*  Yaw       PRB YAW              CHAN 24         Reddat(1,16)     *
2015  !*  Temp      TOTAL TEMP(PLENUM)   CHAN 10         Reddat(1,17)     *
2020  !*  Pa        ATMOSPHERIC PRESS    INPUT           Reddat(1,18)     *
2025  !*                                                                  *
2030  !*                                                                  *
2035  !*******************************************************************
2040  !*******************DATA REDUCTION**********************************
2045  DIM Calc(100,25)
2050  MAT Calc= (0)
2055  Pinitial=0                        !INITIALIZES CONDITIONS FOR ENSEMBLE
2060                                    !CALCULATIONS IN SUBROUTINE ENSEMBLE.
2065  Tinitial=0
2070  Painitial=0
2071  INPUT "INPUT VERNIER READING WHEN PROBE BAR IS HORIZONTAL",Betah
2075  FOR N=1 TO 100
2080  ENTER @Pathl,N;Reddat(*)          !ARRAY ENTERED RANDOMLY
2085  ON END @Pathl GOTO Printcalcl
2090  Ptare=Reddat(1,1)                !REASSIGNMENT OF ARRAY ELEMENTS TO
2095                                    !TO IDENTIFIABLE QUANTITIES USED IN
2100                                    !SUBROUTINE CALCULATIONS.
2105  Pcal=Reddat(1,2)
2110  Pp=Reddat(1,3)
2115  Ps=Reddat(1,4)
2120  P1=Reddat(1,5)
2125  P2=Reddat(1,6)
2130  P3=Reddat(1,7)
2135  P23=(P2+P3)/2
2140  P4=Reddat(1,8)
2145  P5=Reddat(1,9)
2150  Ptp=Reddat(1,10)
2155  Psp=Reddat(1,11)
2160 !BLANK=Reddat(1,12)
2165 !BLANK=Reddat(1,13)
2170 !BLANK=Reddat(1,14)
2175  Posit=Reddat(1,15)
2180  Betaf=Reddat(1,16)
2185  Temp=Reddat(1,17)
2190  Pa=Reddat(1,18)
2191  Yaw=40.45+(Betaf-Betah)
2195  !CALCULATE BETA AND GAMMA COEFFICIENTS
2200  CALL Bgcalc(Pa,P1,P23,P4,P5,Beta,Gamma)
2205  !CALCULATE THE ENSEMBLE REFERENCE VALUES OF PPLENUM,PLENUM TEMP AND PA.
2210 CALL Ensemble(Pp,Pinitial,Pa,Painitial,Temp,Tinitial,Ppavg,Paavg,Tempavg,N)
2215  !CALCULATE Xvel AND Phi
2220  CALL Xphicalc(Beta,Gamma,Xvel,X(*),Phi,P(*))
2225  !CALCULATE Xref
2230  CALL Xrefcalc(Pa,Pp,G,Xref)
2235  !CALCULATE Tempstat
2240  CALL Tempstatcalc(Xvel,Temp,Tempstat)
2245  !CALCULATE [illegible]
```

TABLE B1 (CONTINUED)

```
2250  CALL Qvrefcalc(Xref,Cp,Temp,G,Pp,Pa,Qref,Vref)
2255  !CALCULATE VELOCITY AND MACH # AND Q
2260  CALL Vmqcalc(Xvel,Cp,Temp,G,Vel,Mach,Pl,Pa,Q)
2265  ! CALCULATE THE INTEGRAND FOR THE AVDR EXPRESSION
2270  CALL Kncalc(Pa,Pl,Pp,Xvel,Xref,G,Yaw,Kn)
2275  ! CALCULATE THE COEFFICIENT OF PRESSURE TERMS TO BE MASS AVERAGED.
2280  ! THESE TERMS ARE USED IN THE CALCULATION OF THE LOSS COEFFICIENT.
2285  CALL Coefpress(Pl,Pp,Pa,Xvel,G,Cps,Cpt)
2290  !CALCULATE THE  QUANTITIES TO BE MASS AVERAGED. MULTIPLY THESE VALUES
2295  !BY Kn TO GET THE INTEGRAND REQUIRED TO CALCULATE THE MASS AVERAGED CP'S
2300  CALL Cpintegrand(Pp,Pl,Pa,G,Xvel,A,B,Kn)
2305  !CALCLULATE Pp-Pl/Qref FOR PLOTS
2310  CALL Prefqref(Pp,Pl,Qref,Pq)
2315  ! CALCULATE STATIC PRESSURE
2320  CALL Staticpress(Pl,Pa,Xvel,G,Ps)
2325  !CALCULATE VISCOSITY
2330  CALL Viscyou(Temp,Tempstat,U)
2335  !CALCULATE INTEGRAND FOR REYNOLDS NO
2340  CALL Reintegrand(Kn,U,Yaw,Ire)
2345  !DEFINE AN ARRAY TO STORE CALCULATED VALUES
2350  Calc(N,1)=Posit
2355  Calc(N,2)=Beta
2360  Calc(N,3)=Gamma
2365  Calc(N,4)=Phi
2370  Calc(N,5)=Xvel
2375  Calc(N,6)=Xref
2380  Calc(N,7)=Vel
2385  Calc(N,8)=Mach
2390  Calc(N,9)=Yaw
2395  Calc(N,10)=Kn
2400  Calc(N,11)=Cpt
2405  Calc(N,12)=Cps
2410  Calc(N,13)=Qref
2415  Calc(N,14)=Vref
2420  Calc(N,15)=Q
2425  Calc(N,16)=A
2430  Calc(N,17)=B
2435  Calc(N,18)=Pq
2440  Calc(N,19)=Pa
2445  Calc(N,20)=Ps
2450  Calc(N,21)=U
2455  Calc(N,22)=Ire
2456  Calc(N,23)=Pp
2457  Calc(N,24)=Pl
2460  Knaray(N)=Calc(N,10)                 !WANT TO STORE THE Kn VALUE IN AN
2465                                       !ARRAY FOR MASS AVERAGING CALCULATIONS
2470  Prbpos(N)=Calc(N,1)                  !"" ""
2475  Aaray(N)=Calc(N,16)                  !"" ""
2480  Baray(N)=Calc(N,17)                  !"" ""
2485  Caray(N)=Calc(N,22)
2490  Scan=N
2491  NEXT N
2496 Printcalc!:  OFF END @Path1
2498  !CALCULATE ENSEMBLE AVERAGE OF XREF
2499  CALL Xrefensemble(Paavg,Ppavg,G,Xrefavg)
2500  !CALCULATE ENSEMBLE AVERAGE OF VREF
2501  CALL Vrefensemble(Xrefavg,Cp,Tempavg,Vrefavg)
2502  !CALCULATE ENSEMBLE AVERAGE OF QREF
2503  CALL Qrefensemble(Paavg,Ppavg,G,Xrefavg,Qrefavg)
2504  !CALCULATE THE ENSEMBLEAVE OF STATIC TEMP
2505  CALL Tempstatensembl(Tempavg,Xrefavg,Tempstatavg)
2506  !CALCULATE THE ENSEMBLE AVE OF VISCOSITY
2507  CALL Murefensemble(Tempstatavg,Muref)
2508  Calc(1,25)=Ppavg
```

TABLE B1 (CONTINUED)

```
2509  Calc(2,25)=Paavg
2510  Calc(3,25)=Xrefavg
2512  PRINT "**********************************************************"
2513  PRINT ""
2514  PRINT "ENTER THE LIMITS OF INTEGRATION i.e., THE LOWEST TO THE "
2515  PRINT "HIGHEST SCAN NUMBER DESIRED FOR REYNOLDS CALCULATION."
2516  PRINT ""
2517  PRINT "************************************************************"
2518  PRINT ""
2519  PRINT "************************************************************"
2520  PRINT ""
2521  PRINT "ENTER THE LOW SCAN"
2522  INPUT Lowpoint
2523  PRINT "*************************************************************"
2524  PRINT ""
2525  PRINT "ENTER THE HIGH SCAN"
2526  INPUT Hipoint
2527  LOADSUB ALL FROM "/CLASSICK/ROUTINES/LOSSCALC"
2528  !INTEGRATE I
2529  CALL Datint(Lowpoint,Hipoint,Caray(*),Prbpos(*),Iintg)
2530  Re=12*1.67*(((Ppavg+Paavg)/27.76)/(53.3*Tempavg))*(Vrefavg/Muref)*Iintg
2531  PRINT "************************************************************"
2532  PRINT ""
2533  PRINT "ALIGN PAPER IN THE PRINTER. WHEN READY FOR A HARDCOPY OF THE "
2534  PRINT ""
2535  PRINT "CALCULATED DATA, PRESS ""REDUCED DATA"" ."
2536  PRINT ""
2537  PRINT "*************************************************************"
2538  ON KEY 4 LABEL "REDUCED DATA" GOTO Prntdatal
2539 Spin3:  GOTO Spin3
2540 Prntdatal: PRINTER IS Prnter
2541  PRINT "*****************************************"
2542  PRINT "FILE   ",Calcfile$
2543  PRINT "*****************************************"
2544  PRINT ""
2545  PRINT "*****************************************************************
2546  PRINT ""
2547  PRINT "SCAN   PRB        BETA          GAMMA         PHI            Xvel
2548  PRINT "        POSIT"
2549  FOR N=1 TO Scan
2550  PRINT USING "4D,3X,4D.2D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE
2551  NEXT N
2552  PRINT ""
2553  PRINT "*****************************************************************
2554  PRINT ""
2555  PRINT "SCAN   Vel           Vref          Q             Qref          MACH
2556  PRINT "
2557  FOR N=1 TO Scan
2558  PRINT USING "4D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,2X,MD.3DE,2X,MD.3D
2559  NEXT N
2560  PRINT ""
2561  PRINT "*****************************************************************
2562  PRINT ""
2563  PRINT "SCAN   Pref-Pt/Qref      U            Ire"
2564  FOR N=1 TO Scan
2565  PRINT USING "4D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE";N,Calc(N,18),Calc(N,21),Cal
2566  NEXT N
2567  PRINT ""
2568  PRINT "*****************************************************************
2569  PRINT ""
2570  PRINT " ENSEMBLE AVERAGES"
2571  PRINT ""
2572  PRINT "PPAVG            PAAVG            TEMPAVG      XREFAVG          VREFAVG
2573  PRINT USING "MD.3DE,5X,M3D.2DE,5X,3D.2D,5X,MD.3DE,5X,MD.3DE,3X,MD.3DE";Ppa
```

TABLE B1 (CONTINUED)

```
2574  PRINT "MUREF            TEMPSTATAVG"
2575  PRINT USING "MD.3DE,3X,MD.3DE";Muref,Tempstatavg
2576  PRINT ""
2577  PRINT "REYNOLDS NO"
2578  PRINT USING "D.4DE";Re
2579  PRINT "*************************************************************"
2580  PRINTER IS Scren
2581  OUTPUT @Path4;Calc(*)                  !SERIAL OUTPUT STATEMENT.
2582  END IF
2583  PRINT "*************************************************************"
2584  PRINT ""
2585  PRINT "TO CALCULATE THE CP'S FOR THE BLADE DATA, PRESS ""BLADE CP'S"""
2586  PRINT " PRESS ""GO ON"" TO CONTINUE."
2587  PRINT ""
2588  PRINT "**************************************************************
2589  ON KEY 1 LABEL "BLADE CP'S" GOTO Calculatecp
2590  ON KEY 4 LABEL "GO ON" GOTO Loadoption2
2591 Spin4:  GOTO Spin4
2592 Calculatecp:  MASS STORAGE IS "/CLASSICK/REDDATA"
2593  PRINT ""
2594  PRINT "************************************************************"
2595  PRINT ""
2596  PRINT "ENTER THE FILE NAME OF THE BLADE DATA SCALED IN ENGINEERING UNITS"
2597  INPUT Sclbladfile$
2598  PRINT "************************************************************"
2599  ASSIGN @Path5 TO Sclbladfile$
2600  PRINT ""
2601  PRINT "ENTER THE FILE NAME TO STORE THE MASS AVERAGED CP'S CALCULATED"
2602  PRINT "FROM THE BLADE DATA."
2603  INPUT Bladcalc$
2604  CREATE BDAT Bladcalc$,100
2605  ASSIGN @Path6 TO Bladcalc$
2606  DIM Prntdata(1,48)             !DIMENSION STATMENTS FOR BLADE ARRAYS
2607                                 !ARE HERE SO ARRAY SPACE IS ONLY ASSIGNED
2608                                 !IF BLADE OPTION IS SELECTED.
2609  DIM Cpmassavg(48)
2610  MAT Cpmassavg= (0)
2611  MAT Prntdata= (0)
2612  PRINT "********************************************************"
2613  PRINT ""
2614  PRINT "ENTER THE LIMITS OF INTEGRATION i.e., THE LOWEST TO THE "
2615  PRINT "HIGHEST SCAN NUMBER DESIRED FOR BLADE CP'S"
2616  PRINT ""
2617  PRINT "**********************************************************"
2618  PRINT ""
2619  PRINT "**********************************************************"
2620  PRINT ""
2621  PRINT "ENTER THE LOW SCAN"
2622  INPUT Lowpoint
2623  PRINT "**********************************************************"
2624  PRINT ""
2625  PRINT "ENTER THE HIGH SCAN"
2626  INPUT Hipoint
2627  !INTEGRATE A
2628  CALL Datint(Lowpoint,Hipoint,Aaray(*),Prbpos(*),Aintg)
2629  !INTEGRATE B
2630  CALL Datint(Lowpoint,Hipoint,Baray(*),Prbpos(*),Bintg)
2631  !INTEGRATE Kn
2632  CALL Datint(Lowpoint,Hipoint,Knaray(*),Prbpos(*),Knintg)
2633  AI=Aintg/Knintg
2634  BI=Bintg/Knintg
2635  ENTER @Path5;Prntdata(*)
2636  Po=Prntdata(1,3)
2637  FOR N=Firstbladeprt TO Lastbladeprt !OBTAINED FROM PORT ASSIGNMENT SHEET
```

array assignment section of "CALC." These changes are shown in lines 2071 and 2191 of Table B1.

Modification to provide for mixed-out flow loss required subroutine calls Xrefensemble, Vrefensemble, Tempstatensemble, to calculate values Y_{ref}, V_{ref} and T_{sref} needed for evaluation of the integrals as defined in Appendix D. The subroutines required are contained in "SUBCALC." Additionally most values had to be placed in arrays for the proper passing to "LOSS." Lines 2350-2510 of Table B1 contain the changes to "CALC." Table B2 is a listing of "SUBCALC."

2. "LOSS" Changes

The "LOSS" program was modified to perform fully-mixed-out flow loss calculations in addition to the previously programmed mass averaged loss calculation of Classick [Ref. 6]. This required the change of variables from simple to array variables, the addition of five subroutines and subroutine calls, and the associated print and format procedures to produce the additional output.

The pressure, dimensionless-velocity, yaw angles and position variables were assigned to an array to allow the subsequent calculations discussed in Appendix D. This allowed for proper passing of upstream and downstream values to the appropriate subroutines. Lines 740-1290 of Table B3 are where the changes occurred.

TABLE B2

SUBCALC PROGRAM LISTING

```
10   !FILE SUBCALC
15   !THIS FILE CONTAINS ALL THE CALCULATION SUBROUTINES CALLED BY THE
20   !DATA REDUCTION PROGRAM CALC.
25   SUB Bgcalc(Pa,P1,P23,P4,P5,Beta,Gamma)
30   Beta=(P1-P23)/(P1+Pa)
35   Gamma=(P4-P5)/(P1-P23)
40   SUBEND
45   SUB Xphicalc(Beta,Gamma,Xvel,X(*),Phi,P(*))
50   OPTION BASE 1
55   DIM E(6)
60   DIM F(6)
65   MAT E= (0)
70   MAT F= (0)
75   FOR J=1 TO 6
80   E(J)=X(1,J)+X(2,J)*Gamma+X(3,J)*Gamma^2+X(4,J)*Gamma^3+X(5,J)*Gamma^4+X(6,
85   F(J)=P(1,J)+P(2,J)*Gamma+P(3,J)*Gamma^2+P(4,J)*Gamma^3+P(5,J)*Gamma^4+P(6,
90   NEXT J
95   Xvel=E(1)+E(2)*Beta+E(3)*Beta^2+E(4)*Beta^3+E(5)*Beta^4+E(6)*Beta^5
100  Phi=F(1)+F(2)*Beta+F(3)*Beta^2+F(4)*Beta^3+F(5)*Beta^4+F(6)*Beta^5
105  SUBEND
110  SUB Vmqcalc(Xvel,Cp,Temp,G,Vel,Mach,P1,Pa,Q)
115  Vel=Xvel*(2*Cp*778*32.174*Temp)^.5
120 Mach=(((Xvel^2)/(1-Xvel^2))*(2/(G-1)))^.5
125  Q=(P1+Pa)*(G/(G-1))*Xvel^2*((1-Xvel^2)^(1/(G-1)))
130  SUBEND
135  SUB Xrefcalc(Pa,Pp,G,Xref)
140  Xref=(1-(Pa/(Pp+Pa))^((G-1)/G))^.5
145  SUBEND
150  SUB Kncalc(Pa,P1,Pp,Xvel,Xref,G,Yaw,Kn)
155        Kn=((P1+Pa)/(Pp+Pa))*(Xvel/Xref)*(((1-Xvel^2)/(1-Xref^2))^(1/(G-1)))
160  SUBEND
165  SUB Coefpress(P1,Pp,Pa,Xvel,G,Cps,Cpt)
170  Cpt=(P1+Pa)/(Pp+Pa)
175  Cps=((P1+Pa)*((1-Xvel^2)^(G/(G-1))))/(Pp+Pa)
180  SUBEND
185  SUB Ensemble(Pp,Pinitial,Pa,Painitial,Temp,Tinitial,Ppavg,Paavg,Tempavg,N)
190  Ppe=Pp+Pinitial
195  Ppavg=Ppe/N
200  Pinitial=Ppe
205  Te=Temp+Tinitial
210  Tempavg=Te/N
215  Tinitial=Te
220  Pae=Pa+Painitial
225  Paavg=Pae/N
230  Painitial=Pae
235  SUBEND
240  SUB Xrefensemble(Paavg,Ppavg,G,Xrefavg)
245  Xrefavg=(1-((Paavg)/(Ppavg+Paavg))^((G-1)/G))^.5
250  SUBEND
255  SUB Vrefensemble(Xrefavg,Cp,Tempavg,Vrefavg)
260  Vrefavg=Xrefavg*(2*Cp*Tempavg*778*32.174)^.5
265  SUBEND
270  SUB Qrefensemble(Paavg,Ppavg,G,Xrefavg,Qrefavg)
275  Qrefavg=(Ppavg+Paavg)*(G/(G-1))*Xrefavg^2*(1-Xrefavg^2)^(1/(G-1))
280  SUBEND
285  SUB Qvrefcalc(Xref,Cp,Temp,G,Pp,Pa,Qref,Vref)
290  Vref=Xref*(2*Cp*778*32.174*Temp)^.5
295  Qref=(Pa+Pp)*(G/(G-1))*(Xref^2)*((1-Xref^2)^(1/(G-1)))
300  SUBEND
305  SUB Cpintegrand(Pp,P1,Pa,G,Xvel,A,B,Kn)
310  M=Pp/((P1+Pa)*(G/(G-1))*Xvel^2*((1-Xvel^2)^(1/(G-1))))
315  N1=(Pa/(P1+Pa))-((1-Xvel^2)^(G/(G-1)))
320  N2=(G/(G-1))*Xvel^2*((1-Xvel^2)^(1/(G-1)))
325  N=N1/N2
```

TABLE B2 (CONTINUED)

```
330   A=M*Kn
335   B=N*Kn
340   SUBEND
345   SUB Cpcalc(A1,B1,Pp,Plocal,C)
350   C=((Plocal/Pp)*A1)+B1
355   SUBEND
360   SUB Staticpress(P1,Pa,Xvel,G,Ps)
365   Ps=(P1+Pa)*(1-Xvel^2)^(G/(G-1))
370   SUBEND
375   SUB Prefqref(Pp,P1,Qref,Pq)
380   Pq=(Pp-P1)/Qref
385   SUBEND
390   SUB Viscyou(Temp,Tempstat,U)
395   U=((Temp/Tempstat)^1.5)*((198.72+Tempstat)/(198.72+Temp))
400   SUBEND
405   SUB Reintegrand(Kn,U,Yaw,Ire)
410   Ire=(Kn/COS(Yaw))*U
415   SUBEND
420   SUB Tempstatcalc(Xvel,Temp,Tempstat)
425   Tempstat=Temp*(1-(Xvel^2))
430   SUBEND
435   SUB Tempstatensembl(Tempavg,Xrefavg,Tempstatavg)
440   Tempstatavg=Tempavg*(1-(Xrefavg^2))
445   SUBEND
450   SUB Murefensemble(Tempstatavg,Muref)
455   Muref=((.063379*Tempstatavg^1.5)/(198.72+Tempstatavg))*1.153E-5
460   SUBEND
```

TABLE B3

LOSS PROGRAM LISTING

```
10   !PROGRAM LOSS6
20   !THIS PROGRAM USES VALUES FROM THE CALC ARRAYS GENERATED BY REDUCING
30   !SCALED DATA IN PROGRAM CALC. SUBROUTINES INTEGRATE THESE VALUES AND A
40   !STATIC PRESSURE RISE COEFFICIENT,AVDR & LOSS COEFFICIENT IS CALCULATED.
50   !MUCH OF THE CODING WAS PREVIOUSLY COMMENTED ON IN PROGRAM ACQUIRE AND
60   !PROGRAM CALC.
70   OPTION BASE 1
80   DIM Calcl(100,25)              !NOTE THAT u AND l DESIGNATORS DISTINGUISH
90                                  !THOSE VALUES FROM UPPER SURVEY AND LOWER
100                                 !SURVEY STATIONS RESPECTIVELY.
110  DEG
120  G=1.4
130  Scren=1
140  Prnter=701
150  DIM Calcu(100,75)
160  DIM Positl(100)
170  DIM Positu(100)
180  DIM Cptxkn(100)                !COMBINED VALUES TO MAKE THE INTEGRATIONS
190  DIM Cptuxknu(100)              !MORE EXPLICIT TO THE PROGRAMMER.
200  DIM Cpsxkn(100)
210  DIM Kn(100)
220  DIM Knu(100)
230  DIM Yxkn(100)
240  DIM Zxknu(100)
250  DIM Pau(100)
251  DIM Pal(100)
260  DIM Xl(100)
270  DIM Xlref(100)
280  DIM Plref(100)
290  DIM Ptl(100)
300  DIM Yawl(100)
310  DIM Xu(100)
320  DIM Xuref(100)
330  DIM Puref(100)
340  DIM Ptu(100)
350  DIM Yawu(100)
360  MAT Calcl= (0)
370  MAT Calcu= (0)
380  MAT Positl= (0)
390  MAT Positu= (0)
400  MAT Cptxkn= (0)
410  MAT Cptuxknu= (0)
420  MAT Cpsxkn= (0)
430  MAT Kn= (0)
440  MAT Knu= (0)
450  MAT Yxkn= (0)
460  MAT Zxknu= (0)
470  MAT Pau= (0)
471  MAT Pal= (0)
480  MAT Xl= (0)
490  MAT Xlref= (0)
500  MAT Plref= (0)
510  MAT Ptl= (0)
520  MAT Yawl= (0)
530  MAT Xu= (0)
540  MAT Xuref= (0)
550  MAT Puref= (0)
560  MAT Ptu= (0)
570  MAT Yawu= (0)
580  LOADSUB ALL FROM "/CLASSICK/ROUTINES/LOSSCALC"
581  LOADSUB ALL FROM "/CLASSICK/ROUTINES/LOSSCALC1"
590  LOADSUB ALL FROM "/CLASSICK/ROUTINES/SUBMIXLOSS1"
600  MASS STORAGE IS "/CLASSICK/REDDATA"
610  PRINTER IS Prnter
620  PRINT "LOSS CALCULATION RESULTS FOR STATION TWO AND MIXED FLOW RESULTS."
630  PRINT "******************************************************************"
```

TABLE B3 (CONTINUED)

```
640   PRINTER IS Scren
650   PRINT "ENTER THE NAME OF THE FILE CONTAINING THE CALCULATED DATA FROM THE"
660   PRINT "LOWER PROBE"
670   PRINT "*************************************************************"
680   INPUT Calclfile$
690   PRINT "ENTER IN THE HIGHEST SCAN TAKEN FOR LOWER SURVEY"
700   PRINT "*************************************************************"
710   INPUT Scanl
720   ASSIGN @Path1 TO Calclfile$
730   ENTER @Path1;Calcl(*)
740   FOR N=1 TO Scanl
750   Posit(N)=Calcl(N,1)
760   Kn(N)=Calcl(N,10)
770   Cpt=Calcl(N,11)
780   Cps=Calcl(N,12)
790   Pal(N)=Calcl(N,19)
800   Psl=Calcl(N,20)
810   Xl(N)=Calcl(N,5)
820   Xlref(N)=Calcl(N,6)
830   Plref(N)=Calcl(N,23)
840   Ptl(N)=Calcl(N,24)
850   Yawl(N)=Calcl(N,9)
860   Ql=Calcl(N,15)
900   Y=(Pal(N)-Psl)/Ql
910   Cptxkn(N)=Cpt*Kn(N)
920   Cpsxkn(N)=Cps*Kn(N)
930   Yxkn(N)=Y*Kn(N)
940   NEXT N
950 Skipy:   PRINT ""
960   Plrefavg=Calcl(1,25)
970   Palavg=Calcl(2,25)
980   Xlrefavg=Calcl(3,25)
990   PRINT "ENTER THE NAME OF THE FILE CONTAINING THE CALCULATED DATA FROM THE"
1000  PRINT "UPPER PROBE"
1010  PRINT "*************************************************************"
1020 INPUT Calcufile$
1030  PRINT "ENTER IN THE HIGHEST SCAN TAKEN FOR UPPER SURVEY"
1040  PRINT "*************************************************************"
1050  INPUT Scanu
1060 ASSIGN @Path2 TO Calcufile$
1070 ENTER @Path2;Calcu(*)
1080 FOR N=1 TO Scanu
1090 Positu(N)=Calcu(N,1)
1100 Knu(N)=Calcu(N,10)
1110 Cptu=Calcu(N,11)
1120 Pau(N)=Calcu(N,19)
1130 Psu=Calcu(N,20)
1140 Qu=Calcu(N,15)
1150 Xu(N)=Calcu(N,5)
1160 Xuref(N)=Calcu(N,6)
1170 Puref(N)=Calcu(N,23)
1180 Ptu(N)=Calcu(N,24)
1190 Yawu(N)=Calcu(N,9)
1210 Z=(Psu-Pau(N))/Qu
1220 Cptuxknu(N)=Cptu*Knu(N)
1230 Zxknu(N)=Z*Knu(N)
1240 NEXT N
1250 Skipz:PRINTER IS Prnter
1260 PRINT "USING FILES ",Calclfile$," ",Calcufile$
1270 Purefavg=Calcu(1,25)
1280 Pauavg=Calcu(2,25)
1290 Xurefavg=Calcu(3,25)
1300 PRINT ""
1310 PRINT "XLREFAVG    PLREFAVG  PALAVG"
1320 PRINT USING "MD.3DE,1X,MD.3DE,MD.3DE";Xlrefavg,Plrefavg,Palavg
1330 PRINT ""
```

TABLE B3 (CONTINUED)

```
1340 PRINT "XUREFAVG     PUREFAVG  PAUAVG"
1350 PRINT USING "MD.3DE,1X,MD.3DE,MD.3DE";Xurefavg,Purefavg Pauavg
1360 PRINT ""
1370 PRINTER IS Scren
1380 PRINT ""
1390 PRINT "ENTER THE LIMITS OF INTEGRATION FOR THE LOWER PROBE SURVEY"
1400 PRINT ""
1410 PRINT "****************************************************************"
1420  INPUT "ENTER THE FIRST POINT",Lowpointl
1430  INPUT "ENTER THE LAST POINT",Hipointl
1440  ! CALL THE INTEGRATION ROUTINE
1450  CALL Datint(Lowpointl,Hipointl,Kn(*),Posit(*),Denominator)
1460  CALL Datint(Lowpointl,Hipointl,Cptxkn(*),Posit(*),Intega)
1470  CALL Datint(Lowpointl,Hipointl,Cpsxkn(*),Posit(*),Integc)
1480  CALL Datint(Lowpointl,Hipointl,Yxkn(*),Posit(*),Integy)
1490  CALL Integrals(Ptl(*),Xl(*),Pal(*),Plref(*),Xlref(*),Yaul(*),Posit(*),Hipo
1500  PRINT ""
1510  PRINT "ENTER THE LIMITS OF INTEGRATION FOR THE UPPER PROBE SURVEY"
1520  PRINT ""
1530  PRINT "****************************************************************"
1540 INPUT "ENTER THE FIRST POINT",Lowpointu
1550 INPUT "ENTER THE LAST POINT",Hipointu
1560 CALL Datint(Lowpointu,Hipointu,Knu(*),Positu(*),Numerator)
1570 CALL Datint(Lowpointu,Hipointu,Cptuxknu(*),Positu(*),Integb)
1580 CALL Datint(Lowpointu,Hipointu,Zxknu(*),Positu(*),Integz)
1590 CALL Integrals(Ptu(*),Xu(*),Pau(*),Puref(*),Xuref(*),Yawu(*),Positu(*),Hipo
1600 PRINTER IS Prnter
1610 PRINT " INTEGA      INTEGC      INTEGY      INTEGB      INTEGZ     NUMERATOR"
1620 PRINT USING "MD.3DE,1X,MD.3DE,1X,MD.3DE,1X,MD.3DE,1X,MD.3DE,MD.3DE";Intega,
1660 PRINT ""
1670 PRINT "DENOMINATOR"
1680 PRINT USING "MD.3DE";Denominator
1690 PRINT ""
1700 PRINT "--------------------------------------------------------------"
1710 Cp2=(Integz/Denominator)+(Integy/Denominator)
1720 Avdr=Numerator/Denominator
1730 PRINT "STATION TWO RESULTS"
1740 PRINT "___________________"
1750 PRINT "STATIC PRESSURE RISE COEFFICIENT"
1760 PRINT USING "MD.3DE";Cp2
1770 PRINT ""
1780  PRINT "AVDR"
1790 PRINT USING "MD.3DE";Avdr
1800 PRINT ""
1810  W=(Intega-(1/Avdr)*(Integb))/(Intega-Integc)
1820  PRINT "LOSS COEFFICIENT"
1830  PRINT USING "MD.3DE";W
1840  PRINT ""
1850  PRINT "-------------------------------------------------------------"
1860  PRINT ""
1870  PRINT "THE FOLLOWING IS FOR MIXED FLOW RESULTS"
1880  PRINT ""
1890  PRINT "-------------------------------------------------------------"
1891  PRINT " I1AVGL      I2AVGL      I3AVGL      I1AVGU      I2AVGU      I3AVGU"
1892  PRINT USING "MD.3DE,1X,MD.3DE,1X,MD.3DE,1X,MD.3DE,1X,MD.3DE,1X,MD.3DE";I1a
1893  PRINT ""
1900  CALL Conscalc(I1avgl,I2avgl,I3avgl,Xlrefavg,Aavgl,Bavgl,Cavgl,Davgl,Eavgl)
1901  PRINT "AAVGL       BAVGL       CAVGL       DAVGL       EAVGL"
1902  PRINT USING "MD.3DE,1X,MD.3DE,1X,MD.3DE,1X,MD.3DE,1X,MD.3DE";Aavgl,Bavgl,C
1903  PRINT ""
1910  CALL Conscalc(I1avgu,I2avgu,I3avgu,Xurefavg,Aavgu,Bavgu,Cavgu,Davgu,Eavgu)
1911  PRINT "AAVGU       BAVGU       CAVGU       DAVGU       EAVGU"
1912  PRINT USING "MD.3DE,1X,MD.3DE,1X,MD.3DE,1X,MD.3DE,1X,MD.3DE";Aavgu,Bavgu,C
1913  PRINT ""
1920  CALL Mixflow(Aavgl,Bavgl,Cavgl,Davgl,Eavgl,Xlrefavg,I1avgl,Palavg,Xlmixflo
1930  CALL Mixflow(Aavgu,Bavgu,Cavgu,Davgu,Eavgu,Xurefavg,I1avgu,Pauavg,Xumixflo
```

TABLE B3 (CONTINUED)

```
1950 PRINT USING "MD.3DE,MD.3DE,1X,MD.3DE,1X,MD.3DE";Xlmixflow,Yawlmixflow,Ptlr
1960 PRINT ""
1970 PRINT "XMIXFLOW  YAWMIXFLOW PTRATIO    PSRATIO     FOR UPPER STATION"
1980 PRINT USING "MD.3DE,MD.3DE,1X,MD.3DE,1X,MD.3DE";Xumixflow,Yawumixflow,Ptur
1990 CALL Mixloss(Pturatio,Ptlratio,Pslratio,Palavg,Pauavg,Plrefavg,Purefavg,Wm
1992 CALL Avdrmix(Ptlratio,Pturatio,Xlmixflow,Xumixflow,Xlrefavg,Xurefavg,Yawlm
2000 PRINT ""
2010 PRINT "----------------------------------------------------------------"
2020 PRINT ""
2030 PRINT "MIX FLOW RESULTS"
2040 PRINT "________________"
2050 PRINT ""
2060 PRINT "MIX FLOW STATIC PRESSURE RISE COEFFICIENT"
2070 !PRINT USING "MD.3DE";Cpmixflow
2080 PRINT ""
2090 PRINT "MIX FLOW AVDR"
2100 PRINT USING "MD.3DE";Avdrmixflow
2110 PRINT ""
2120 PRINT "MIX FLOW LOSS COEFFICIENT"
2130 PRINT USING "MD.3DE";Wmixflow
2140 PRINT ""
2150 PRINTER IS Scren
2160 PRINT ""
2170 PRINT "****************************************************************"
2180 PRINT ""
2190 PRINT "                         END OF PROGRAM"
2200 PRINT ""
2210 PRINT "****************************************************************"
2220 END
```

The additional subroutines for the fully-mixed-out loss calculation are in the routine "SUBMIXLOSS." Subroutine "Integrals" is used to calculate the necessary integrals as shown in Appendix D. Subroutine "Conscalc" reduces the integrals to the needed constants for the fully-mixed-flow quadratic equations described in Appendix D. Subroutine "Mixflow" returns the mixed-flow pressure ratios for the mixed loss calculation. Subroutine "Mixloss" provides the mixed-out loss coefficient while subroutine "AVDR" provides the mixed-out axial-velocity-density ratio. Lines 10-640 of Table B4 incorporate these changes.

The print and format statements were added in lines 1610-2150 of Table B3. These changes are shown in Figures B3 and B4 which are the printouts of the loss results for the reference blade and the slotted blade.

B5. PROGRAM LISTINGS

The complete listing of the programs and associated subroutines is given in the Table of Contents for Appendix B. The listed programs are matched with the below identified subroutines:

<u>ACQUIRE</u>	<u>CALC</u>	<u>LOSS</u>
SUBACQUIRE	SUBCALC	SUBLOSS
		SUBMIXLOSS

Plots as listed were printed out using the following plotting programs:

TABLE B4

SUBMIXLOSS PROGRAM LISTING

```
20    !THIS FILE CONTAINS THE CALCULATIONS NEEDED TO FIND THE MIX
30    !FLOW PARAMETERS OF ANY MEASURED STATION
40    !
50    !INTEGRALS FINDS THE I1AVG,I2AVG AND I3AVG VALUES
60    !CONSCALC FINDS THE VALUES OF A,B,C,D,E
70    !MIXFLOW FINDS THE VALUES OF X,TAU, PT RATION AND PS RATIO
80    !MIXLOSS FINDS THE CPT, AVDR AND MIX FLOW LOSS
90    SUB Integrals(Pt(*),X(*),Pa(*),Ptref(*),Xsref(*),tau(*),Posit(*),Hipoint,L
100   OPTION BASE 1
101   G=1.41
110   DIM Integral1(100)
120   DIM Integral2(100)
130   DIM Integral3(100)
140   MAT Integral1= (0)
150   MAT Integral2= (0)
160   MAT Integral3= (0)
170   FOR N=1 TO Scan
180   Integral1(N)=((Pt(N)+Pa(N))*X(N)*(1-X(N)^2)^(1/(G-1))*COS(tau(N)))/((Ptref
190   Integral2(N)=(Integral1(N)*X(N)*SIN(tau(N)))/Xsref(N)
200   Integral3(N)=((Pt(N)+Pa(N))*((1-X(N)^2)^3.5+(7*X(N)^2*(1-X(N)^2)^2.5*COS(t
210   NEXT N
220   CALL Datintl(Lowpoint,Hipoint,Integral1(*),Posit(*),I1)
230   CALL Datintl(Lowpoint,Hipoint,Integral2(*),Posit(*),I2)
240   CALL Datintl(Lowpoint,Hipoint,Integral3(*),Posit(*),I3)
250   I1avg=I1
260   I2avg=I2
270   I3avg=I3
280   SUBEND
290   !-------------------------------------------------------------------
300   SUB Conscalc(I1avg,I2avg,I3avg,xrefavg,A,B,C,D,E)
310   A=Xrefavg*(I2avg/I1avg)
320   B=Xrefavg*(I3avg/I1avg)
330   G=1.41
340   C=((G+1)/(G-1))^2
350   D=2*SQRT(C)*(1-((2*G)/(G-1))*A^2)-B^2
360   E=(1-((2*G)/(G-1))*A^2)^2+B^2*A^2
370   SUBEND
380   !-------------------------------------------------------------------
390   SUB Mixflow(A,B,C,D,E,Xrefavg,I1avg,Paavg,Xmixflow,Taumixflow,Ptratio,Psra
400   G=1.41
410   Xmixflowsqr1=(-D+SQRT(D^2-4*C*E))/(2*C)
420   Xmixflowsqr2=(-D-SQRT(D^2-4*C*E))/(2*C)
430   Xmixflow1=SQRT(Xmixflowsqr1)
440   Xmixflow2=SQRT(Xmixflowsqr2)
450   IF Xmixflow1>Xmixflow2 THEN
460      Xmixflow=Xmixflow2
470   ELSE
480      Xmixflow=Xmixflow1
490   END IF
500   Taumixflow=ASN(A/Xmixflow)
510   Ptratio=(Xrefavg/Xmixflow)*((1-Xrefavg^2)^2.5)/(1-Xmixflow^2)^2.5*(I1avg/C
520   Psratio=Ptratio*(1-Xmixflow^2)^(G/(G-1))
530   SUBEND
540   !-------------------------------------------------------------------
550   SUB Mixloss(Pt2ratio,Pt1ratio,Ps1ratio,Pal,Pau,Plr,Pur,Loss)
570   Loss=(Pt1ratio-Pt2ratio)/(Pt1ratio-Ps1ratio)
580   SUBEND
590   !-------------------------------------------------------------------
600   SUB Avdrmix(Ptlratio,Pturatio,Xlmix,Xumix,Xlref,Xuref,taul,tauu,Avdr)
610   Klmixflow=Ptlratio*(Xlmix/Xlref)*((1-Xlmix^2)/(1-Xlref^2))^2.5*COS(taul)
620   Kumixflow=Pturatio*(Xumix/Xuref)*((1-Xumix^2)/(1-Xuref^2))^2.5*COS(tauu)
630   Avdr=Kumixflow/Klmixflow
640   SUBEND
```

```
LOSS CALCULATION RESULTS FOR STATION TWO AND MIXED FLOW RESULTS.
****************************************************************
USING FILES          L-04MAY7CALC                    U-01JUNCALC

XLREFAVG     PLREFAVG   PALAVG
 9.342E-02   1.267E+01  4.066E+02

XUREFAVG     PUREFAVG   PAUAVG
 9.318E-02   1.263E+01  4.074E+02

 INTEGA      INTEGC      INTEGY      INTEGB      INTEGZ      NUMERATOR
 2.325E+00   2.225E+00   1.018E+00   2.352E+00  -1.177E-01   2.376E+00

DENOMINATOR
 2.339E+00

-----------------------------------------------------------------
STATION TWO RESULTS
-------------------
STATIC PRESSURE RISE COEFFICIENT
 3.851E-01

AVDR
 1.016E+00

LOSS COEFFICIENT
 1.014E-01

-----------------------------------------------------------------

THE FOLLOWING IS FOR MIXED FLOW RESULTS

-----------------------------------------------------------------
 I1AVGL      I2AVGL      I3AVGL      I1AVGU      I2AVGU      I3AVGU
 7.798E-01   6.965E-01   1.157E+02   7.918E-01   2.922E-02   1.149E+02

AAVGL       BAVGL       CAVGL       DAVGL       EAVGL
 8.344E-02   1.386E+01   3.455E+01  -1.810E+02   2.245E+00

AAVGU       BAVGU       CAVGU       DAVGU       EAVGU
 3.438E-03   1.352E+01   3.455E+01  -1.711E+02   1.002E+00

XMIXFLOW   YAWMIXFLOW PTRATIO     PSRATIO     FOR LOWER STATION
 1.115E-01 4.845E+01   9.943E-01   9.525E-01

XMIXFLOW   YAWMIXFLOW PTRATIO     PSRATIO     FOR UPPER STATION
 7.658E-02 2.574E+00   9.576E-01   9.385E-01

-----------------------------------------------------------------

MIX FLOW RESULTS
----------------

MIX FLOW STATIC PRESSURE RISE COEFFICIENT

MIX FLOW AVDR
 1.015E+00

MIX FLOW LOSS COEFFICIENT
 8.760E-01
```

Figure B3. Reference Blade Loss Output

```
LOSS CALCULATION RESULTS FOR STATION TWO AND MIXED FLOW RESULTS.
*****************************************************************
USING FILES          L-04MAY7CALC                      U-31MAYMCALC

XLREFAVG     PLREFAVG   PALAVG
 9.342E-02   1.267E+01 4.066E+02

XUREFAVG     PUREFAVG   PAUAVG
 9.315E-02   1.260E+01 4.068E+02

 INTEGA       INTEGC       INTEGY       INTEGB       INTEGZ      NUMERATOR
 2.325E+00   2.225E+00   1.018E+00   2.388E+00  -1.158E-01  2.412E+00

DENOMINATOR
 2.339E+00

-------------------------------------------------------------------
STATION TWO RESULTS
-------------------
STATIC PRESSURE RISE COEFFICIENT
 3.859E-01

AVDR
 1.031E+00

LOSS COEFFICIENT
 8.969E-02

-----------------------------------------------------------------

THE FOLLOWING IS FOR MIXED FLOW RESULTS

-----------------------------------------------------------------
 I1AVGL      I2AVGL      I3AVGL      I1AVGU      I2AVGU      I3AVGU
 7.7[illegible]8E-01   6.965E-01   1.157E+02   8.038E-01   3.136E-02   1.146E+02

AAVGL        BAVGL        CAVGL        DAVGL        EAVGL
 8.344E-02   1.306E+01   3.455E+01  -1.810E+02   2.745E+00

AAVGU        BAVGU        CAVGU        DAVGU        EAVGU
 3.635E-03   1.328E+01   3.455E+01  -1.647E+02   1.002E+00

XMIXFLOW   YAWMIXFLOW PIRATIO     PSRATIO      FOR LOWER STATION
 1.115E-01 4.845E+01  9.943E-01  9.525E-01

XMIXFLOW   YAWMIXFLOW PIRATIO     PSRATIO      FOR UPPER STATION
 7.806E-02 2.669E+00  9.540E-01  9.342E-01

-----------------------------------------------------------------

MIX FLOW RESULTS
----------------

MIX FLOW STATIC PRESSURE RISE COEFFICIENT

MIX FLOW AVDR
 1.031E+00

MIX FLOW LOSS COEFFICIENT
 9.627E-01
```

Figure B4. Slotted Blade Loss Output

Program	Plot
CPBLADEPLOT	Figure 12
BETAPOSIT	Figure 7
PRESSPLOT	Figure 9
VVREFPLOT	Figure 8

The plots are printed using the DUMP GRAP key on the Hewlett Packard keyboard. A simple understanding of the plotting procedures of Reference 10 is needed to ensure proper plots.

B6. DATA LISTING

Table B5 lists the scanivalve port and scanner channel assignments for data acquired using the program "ACQUIRE."

An example of the table of survey data for an upstream survey output by "ACQUIRE" in raw measurement units (volts) is given in Table B6 with the corresponding scaled (engineering units) data output in Table B7. Results of downstream surveys for both reference and slotted blades are similar, with variations occurring only in measurements, scan numbers and scan positions.

The following list provides the reduced data output tables and the corresponding survey position and blade:

Table	Position	Blade
B8	Upstream	Reference
B9	Downstream	Reference
B10	Downstream	Slotted

An example of scaled data output by "ACQUIRE" for a surface pressure scan is given in Table B11. The associated table of pressure coefficients calculated by "CALC" is listed in Table B12.

TABLE B5

SCANIVALVE AND SCANNER CHANNEL ASSIGNMENTS

	5-Hole Probe S.V. # 2	S.V. # 1	ch	SCANNER #2	ch	SCANNER #2
1	P atmospheric	P atmospheric	0	SV1 READ DATA	40	SV1 ADVANCE(step)
2	P calibration	P calibration	1	SV2 " "	41	SV2 "
3	P plenum	P plenum	2		42	
4	P wall static	20B blade(press)	3		43	
5	P1 (probe)	19B	4		44	
6	P2 "	18B	5		45	SV1 RESET(home)
7	P3 "	17B	6		46	SV2 "
8	P4 "	16B	7		47	
9	P5 "	15B	8		48	
10	Ptp Prandtl(total)	14B	9		49	
11	Psp Prandtl(static)	13B	10	Tt(plenum)	50	
12	BLANK	12B	11		51	
13	"	11B	12		52	
14	"	10B	13		53	
15		9B	14		54	
16		8B	15		55	
17		7B	16		56	
18		6B	17		57	
19		5B	18		58	
20		4B	19		59	
21		3B	20		60	
22		2B	21		61	
23		1	22		62	
24		2T(suction side)	23		63	
25		3T	24	YAW XDUCER	64	
26		4T	25		65	
27		5T	26		66	
28		6T	27		67	
29		7T	28		68	
30		8T	29		69	
31		9T	30		70	
32		10T	31		71	
33		11T	32		72	
34		12T	33		73	
35		13T	34		74	
36		14T	35		75	
37		15T	36		76	
38		16T	37		77	
39		17T	38		78	
40		18T	39		79	
41		19T				
42		20T				
43		S1 (partial inst)				
44		S2 (suction side)				
45		S3				
46		P2 (press side)				
47		P3				
48		TRAILING EDGE				

TABLE B6

EXAMPLE RAW DATA FILE PRINTOUT

```
*********************************************
PROBE RAW DATA FILE          L-04MAY7RAW
*********************************************
```

SCAN	PROBE POSIT	1	2	3	4	5
1	0.00	-1.070E-05	-1.120E-05	1.259E-03	-7.314E-04	9.666E-04
2	.10	-1.120E-05	-1.060E-05	1.255E-03	-7.294E-04	9.692E-04
3	.20	-8.400E-06	-8.600E-06	1.250E-03	-7.266E-04	9.678E-04
4	.30	-9.800E-06	-9.400E-06	1.257E-03	-7.338E-04	9.726E-04
5	.40	-1.340E-05	-1.220E-05	1.251E-03	-7.280E-04	9.790E-04
6	.50	-1.300E-05	-1.360E-05	1.250E-03	-7.336E-04	9.838E-04
7	.60	-1.160E-05	-1.300E-05	1.255E-03	-7.284E-04	9.927E-04
8	.70	-1.320E-05	-1.370E-05	1.750E-03	-7.346E-04	9.902E-04
9	.80	-1.220E-05	-1.240E-05	1.258E-03	-7.350E-04	9.918E-04
10	.90	-1.160E-05	-1.180E-05	1.257E-03	-7.322E-04	9.962E-04
11	1.00	-1.180E-05	-1.160E-05	1.254E-03	-7.322E-04	9.960E-04
12	1.10	-3.400E-06	-4.000E-06	1.258E-03	-7.354E-04	1.001E-03
13	1.20	-1.240E-05	-1.120E-05	1.258E-03	-7.392E-04	1.010E-03
14	1.30	-1.000E-05	-1.080E-05	1.260E-03	-7.314E-04	1.013E-03
15	1.40	-9.600E-06	-1.080E-05	1.261E-03	-7.342E-04	1.018E-03
16	1.50	-7.400E-06	-6.000E-06	1.256E-03	-7.328E-04	1.016E-03
17	1.60	-9.200E-06	-9.800E-06	1.267E-03	-7.364E-04	1.034E-03
18	1.70	-8.400E-06	-7.000E-06	1.261E-03	-7.310E-04	1.032E-03
19	1.80	-1.200E-06	-1.400E-06	1.261E-03	-7.370E-04	1.029E-03
20	1.90	-5.600E-06	-5.800E-06	1.253E-03	-7.360E-04	1.033E-03
21	2.00	-2.000E-06	-2.000E-07	1.262E-03	-7.350E-04	1.037E-03
22	2.10	-1.000E-05	-1.070E-05	1.263E-03	-7.368E-04	1.030E-03
23	2.20	-1.340E-05	-1.200E-05	1.255E-03	-7.330E-04	1.073E-03
24	2.30	-1.020E-05	-1.040E-05	1.258E-03	-7.314E-04	1.026E-03
25	2.40	-1.280E-05	-1.120E-05	1.257E-03	-7.337E-04	1.077E-03
26	2.50	-1.120E-05	-1.200E-05	1.255E-03	-7.312E-04	1.021E-03
27	2.60	-1.120E-05	-1.270E-05	1.255E-03	-7.412E-04	1.026E-03
28	2.70	-1.400E-05	-1.600E-05	1.254E-03	-7.390E-04	1.032E-03
29	2.80	-1.000E-05	-1.120E-05	1.258E-03	-8.037E-04	1.035E-03
30	2.90	-1.320E-05	-1.320E-05	1.254E-03	-8.076E-04	1.025E-03
31	3.00	-1.170E-05	-1.200E-05	1.258E-03	-8.036E-04	1.034E-03

```
*****************************************************************************
```

SCAN	6	7	8	9	10	11
1	-8.372E-04	-8.362E-04	-7.734E-04	-9.588E-04	1.077E-03	-7.204E-04
2	-8.386E-04	-8.396E-04	-7.720E-04	-9.604E-04	1.079E-03	-7.178E-04
3	-8.366E-04	-8.346E-04	-7.732E-04	-9.644E-04	1.073E-03	-7.186E-04
4	-8.346E-04	-8.357E-04	-7.604E-04	-9.622E-04	1.076E-03	-7.218E-04
5	-8.360E-04	-8.380E-04	-7.638E-04	-9.676E-04	1.068E-03	-7.182E-04
6	-8.386E-04	-8.384E-04	-7.656E-04	-9.874E-04	1.078E-03	-7.238E-04
7	-8.386E-04	-8.368E-04	-7.636E-04	-9.740E-04	1.074E-03	-7.252E-04
8	-8.378E-04	-8.368E-04	-7.610E-04	-9.782E-04	1.075E-03	-7.240E-04
9	-8.390E-04	-8.386E-04	-7.684E-04	-9.738E-04	1.073E-03	-7.268E-04
10	-8.406E-04	-8.374E-04	-7.642E-04	-9.744E-04	1.076E-03	-7.238E-04
11	-8.364E-04	-8.350E-04	-7.634E-04	-9.710E-04	1.071E-03	-7.204E-04
12	-8.372E-04	-8.348E-04	-7.676E-04	-9.668E-04	1.075E-03	-7.730E-04
13	-8.406E-04	-8.402E-04	-7.722E-04	-9.700E-04	1.081E-03	-7.272E-04
14	-8.338E-04	-8.340E-04	-7.690E-04	-9.617E-04	1.087E-03	-7.246E-04
15	-8.374E-04	-8.382E-04	-7.766E-04	-9.618E-04	1.088E-03	-7.287E-04
16	-8.358E-04	-8.374E-04	-7.758E-04	-9.636E-04	1.084E-03	-7.264E-04
17	-8.397E-04	-8.370E-04	-7.746E-04	-9.670E-04	1.084E-03	-7.226E-04
18	-8.337E-04	-8.374E-04	-7.718E-04	-9.550E-04	1.089E-03	-7.278E-04
19	-8.352E-04	-8.356E-04	-7.738E-04	-9.616E-04	1.079E-03	-7.188E-04
20	-8.344E-04	-8.334E-04	-7.738E-04	-9.498E-04	1.089E-03	-7.388E-04
21	-8.376E-04	-8.354E-04	-7.694E-04	-9.612E-04	1.087E-03	-7.232E-04
22	-8.344E-04	-8.340E-04	-7.656E-04	-9.614E-04	1.078E-03	-7.212E-04
23	-8.306E-04	-8.286E-04	-7.678E-04	-9.606E-04	1.077E-03	-7.220E-04
24	-8.300E-04	-8.288E-04	-7.560E-04	-9.674E-04	1.079E-03	-7.197E-04
25	-8.317E-04	-8.296E-04	-7.532E-04	9.570E-04	1.075E-03	-7.224E-04
26	-8.297E-04	-8.287E-04	-7.407E-04	-9.697E-04	1.075E-03	-7.192E-04
27	-8.332E-04	-8.348E-04	-7.510E-04	-9.758E-04	1.080E-03	-7.246E-04

TABLE B6 (CONTINUED)

28	-8.796E-04	-8.276E-04	-7.446E-04	-9.712E-04	1.075E-03	-7.190E-04
29	-8.794E-04	-8.300E-04	-7.430E-04	-9.787E-04	1.077E-03	-7.246E-04
30	-8.286E-04	-8.268E-04	-7.486E-04	-9.754E-04	1.078E-03	-7.226E-04
31	-8.340E-04	-8.290E-04	-7.466E-04	-9.776E-04	1.073E-03	-7.197E-04

SCAN	12	13	14	YAWCHAN VOLTAGE	TEMPCHAN VOLTAGE	ATMOS PRESSURE
1	-1.800E-06	-8.000E-06	-1.040E-05	4.851E-02	1.221E-03	406.63
2	-4.800E-06	-9.200E-06	-1.260E-05	4.851E-02	1.231E-03	406.63
3	-4.400E-06	-9.400E-06	-1.060E-05	4.849E-02	1.247E-03	406.63
4	-5.000E-06	-1.160E-05	-1.280E-05	4.850E-02	1.256E-03	406.63
5	-7.000E-06	-1.260E-05	-1.500E-05	4.841E-02	1.257E-03	406.63
6	-5.800E-06	-8.400E-06	-1.100E-05	4.836E-02	1.251E-03	406.63
7	-5.400E-06	-1.200E-05	-1.420E-05	4.838E-02	1.250E-03	406.63
8	-7.000E-06	-1.360E-05	-1.460E-05	4.838E-02	1.257E-03	406.63
9	-8.600E-06	-1.300E-05	-1.660E-05	4.837E-02	1.254E-03	406.63
10	-6.800E-06	-1.240E-05	-1.340E-05	4.837E-02	1.259E-03	406.63
11	-8.200E-06	-1.080E-05	-1.140E-05	4.836E-02	1.264E-03	406.63
12	-6.400E-06	-1.180E-05	-1.340E-05	4.857E-02	1.276E-03	406.63
13	-1.080E-05	-1.120E-05	-1.320E-05	4.853E-02	1.275E-03	406.63
14	-3.400E-06	-1.060E-05	-1.200E-05	4.847E-02	1.275E-03	406.63
15	-1.400E-06	-6.600E-06	-1.100E-05	4.847E-02	1.276E-03	406.63
16	-3.000E-06	-9.000E-06	-1.160E-05	4.845E-02	1.281E-03	406.63
17	-3.800E-06	-8.200E-06	-1.000E-05	4.850E-02	1.288E-03	406.63
18	-8.000E-07	-5.200E-06	-7.000E-06	4.849E-02	1.288E-03	406.63
19	-6.000E-06	-1.060E-05	-1.240E-05	4.834E-02	1.307E-03	406.63
20	1.000E-06	4.000E-07	-8.000E-07	4.833E-02	1.299E-03	406.63
21	-6.800E-06	-1.260E-05	-1.380E-05	4.836E-02	1.297E-03	406.63
22	-7.000E-06	-1.300E-05	-1.600E-05	4.838E-02	1.297E-03	406.63
23	-7.400E-06	-1.380E-05	-1.380E-05	4.837E-02	1.311E-03	406.63
24	-7.800E-06	-1.200E-05	-1.540E-05	4.836E-02	1.315E-03	406.63
25	-8.200E-06	-1.280E-05	-1.340E-05	4.834E-02	1.319E-03	406.63
26	[illegible]	-1.780E-05	-1.420E-05	4.834E-02	1.324E-03	406.63
27	-9.200E-06	-1.460E-05	-1.780E-05	4.836E-02	1.331E-03	406.63
28	-8.800E-06	-1.440E-05	-1.400E-05	4.835E-02	1.329E-03	406.63
29	-5.200E-06	-1.300E-05	-1.460E-05	4.831E-02	1.330E-03	406.63
30	-5.400E-06	-1.240E-05	-1.470E-05	4.824E-02	1.338E-03	406.63
31	-6.600E-06	-1.360E-05	-1.560E-05	4.827E-02	1.333E-03	406.63

TABLE B7

EXAMPLE SCALED DATA FILE PRINTOUT

PROBE SCALED DATA FILE L-04MAI7SCI

SCAN	PROBE POSIT	1	2	3	4	5
1	0.00	-1.070E-01	-1.000E-02	1.269E+01	-7.212E+00	9.768E+00
2	.10	-1.120E-01	6.000E-03	1.266E+01	-7.182E+00	9.804E+00
3	.20	-8.400E-02	-2.000E-03	1.758E+01	-7.182E+00	9.752E+00
4	.30	-9.800E-02	4.000E-03	1.262E+01	-7.240E+00	9.824E+00
5	.40	-1.340E-01	1.200E-02	1.264E+01	-7.154E+00	9.924E+02
6	.50	-1.380E-01	2.000E-03	1.272E+01	-7.198E+00	9.976E+00
7	.60	-1.160E-01	-1.400E-02	1.266E+01	-7.168E+00	1.004E+01
8	.70	-1.320E-01	0.000E+00	1.264E+01	-7.214E+00	1.003E+01
9	.80	-1.220E-01	-2.000E-03	1.270E+01	-7.278E+00	1.004E+01
10	.90	-1.160E-01	-2.000E-03	1.268E+01	-7.206E+00	1.008E+01
11	1.00	-1.180E-01	2.000E-03	1.266E+01	-7.204E+00	1.008E+01
12	1.10	-3.400E-02	-6.000E-03	1.262E+01	-7.320E+00	1.004E+01
13	1.20	-1.240E-01	1.200E-02	1.271E+01	-7.268E+00	1.027E+01
14	1.30	-1.000E-01	-8.000E-03	1.270E+01	-7.214E+00	1.023E+01
15	1.40	-9.600E-02	-1.200E-02	1.271E+01	-7.246E+00	1.027E+01
16	1.50	-7.400E-02	6.000E-03	1.264E+01	-7.254E+00	1.024E+01
17	1.60	-9.200E-02	-6.000E-03	1.271E+01	-7.277E+00	1.043E+01
18	1.70	-8.400E-02	1.400E-02	1.269E+01	-7.226E+00	1.041E+01
19	1.80	-1.700E-02	-2.000E-03	1.263E+01	-7.308E+00	1.030E+01
20	1.90	-5.600E-02	-2.000E-03	1.259E+01	-7.304E+00	1.039E+01
21	2.00	-2.002E-02	1.800E-02	1.264E+01	-7.330E+00	1.039E+01
22	2.10	-1.000E-01	-2.000E-03	1.273E+01	-7.268E+00	1.040E+01
23	2.20	-1.340E-01	1.400E-02	1.268E+01	-7.196E+00	1.037E+01
24	2.30	-1.020E-01	-2.000E-03	1.269E+01	-7.212E+00	1.036E+01
25	2.40	-1.290E-01	1.600E-02	1.265E+01	-7.204E+00	1.035E+01
26	2.50	-1.120E-01	-8.000E-03	1.267E+01	-7.200E+00	1.037E+01
27	2.60	-1.120E-01	-1.000E-02	1.266E+01	-7.300E+00	1.037E+01
28	2.70	-1.400E-01	-2.000E-02	1.268E+01	-7.250E+00	1.046E+01
29	2.80	-1.080E-01	-4.000E-03	1.268E+01	-7.974E+00	1.045E+01
30	2.90	-1.320E-01	0.000E+00	1.267E+01	-7.944E+00	1.036E+01
31	3.00	-1.170E-01	-8.000E-03	1.269E+01	-7.984E+00	1.045E+01

SCAN	6	7	8	9	10	11
1	-8.270E+00	-8.260E+00	-7.632E+00	-9.406E+00	1.087E+01	-7.102E+00
2	-8.274E+00	-8.284E+00	-7.608E+00	-9.492E+00	1.090E+01	-7.066E+00
3	-8.282E+00	-8.267E+00	-7.640E+00	-9.560E+00	1.097E+01	-7.107E+00
4	-8.249E+00	-8.254E+00	-7.586E+00	-9.524E+00	1.086E+01	-7.120E+00
5	-8.226E+00	-8.246E+00	-7.504E+00	-9.542E+00	1.081E+01	-7.048E+00
6	-8.248E+00	-8.246E+00	-7.518E+00	-9.606E+00	1.092E+01	-7.100E+00
7	-8.270E+00	-8.257E+00	-7.570E+00	-9.624E+00	1.085E+01	-7.136E+00
8	-8.246E+00	-8.236E+00	-7.478E+00	-9.650E+00	1.080E+01	-7.108E+00
9	-8.268E+00	-8.264E+00	-7.562E+00	-9.616E+00	1.085E+01	-7.146E+00
10	-8.290E+00	-8.250E+00	-7.576E+00	-9.628E+00	1.086E+01	-7.177E+00
11	-8.246E+00	-8.237E+00	-7.516E+00	-9.592E+00	1.083E+01	-7.086E+00
12	-8.338E+00	-8.314E+00	-7.642E+00	-9.634E+00	1.078E+01	-7.196E+00
13	-8.282E+00	-8.278E+00	-7.598E+00	-9.576E+00	1.093E+01	-7.148E+00
14	-8.236E+00	-8.240E+00	-7.590E+00	-9.512E+00	1.097E+01	-7.146E+00
15	-8.278E+00	-8.286E+00	-7.670E+00	-9.572E+00	1.097E+01	-7.186E+00
16	-8.284E+00	-8.300E+00	-7.684E+00	-9.562E+00	1.091E+01	-7.190E+00
17	-8.300E+00	-8.278E+00	-7.654E+00	-9.570E+00	1.093E+01	-7.134E+00
18	-8.230E+00	-8.240E+00	-7.634E+00	-9.466E+00	1.098E+01	-7.194E+00
19	-8.340E+00	-8.344E+00	-7.726E+00	-9.604E+00	1.080E+01	-7.176E+00
20	-8.288E+00	-8.270E+00	-7.680E+00	-9.442E+00	1.094E+01	-7.332E+00
21	-8.356E+00	-8.334E+00	-7.674E+00	-9.592E+00	1.084E+01	-7.2[illegible]E+00
22	[illegible]	-8.2[illegible]E+00	-7.556E+00	-9.5[illegible]E+00	1.088E+01	-7.112E+00
23	-8.172E+00	-8.152E+00	-7.434E+00	-9.477E+00	1.090E+01	-7.086E+00
24	-8.198E+00	-8.186E+00	-7.453E+00	-9.572E+00	1.083E+01	-7.090E+00
25	-8.184E+00	-8.168E+00	-7.404E+00	-9.547E+00	1.088E+01	-7.036E+00
26	-8.180E+00	-8.170E+00	-7.370E+00	-9.580E+00	1.086E+01	-7.080E+00
27	-8.220E+00	-8.236E+00	-7.398E+00	-9.646E+00	1.091E+01	-7.134E+00
28	-8.156E+00	-8.136E+00	-7.306E+00	-9.572E+00	1.089E+01	-7.050E+00

TABLE B7 (CONTINUED)

29	-8.186E+00	-8.192E+00	-7.372E+00	-9.674E+00	1.086E+01	-7.138E+00
30	-8.154E+00	-8.136E+00	-7.354E+00	-9.622E+00	1.091E+01	-7.094E+00
31	-8.228E+00	-8.176E+00	-7.354E+00	-9.664E+00	1.084E+01	-7.080E+00

SCAN	12	13	14	YAW DEG	TEMP (R)	ATMOS PRESS
1	8.400E-02	2.200E-02	-2.000E-03	4.851E+01	5.357E+02	406.63
2	6.400E-02	2.000E-02	-1.400E-02	4.851E+01	5.360E+02	406.63
3	4.000E-02	-1.000E-02	-2.200E-02	4.849E+01	5.365E+02	406.63
4	4.000E-02	-1.800E-02	-3.000E-02	4.850E+01	5.360E+02	406.63
5	6.400E-02	8.000E-03	-1.000E-02	4.841E+01	5.369E+02	406.63
6	8.000E-02	5.400E-02	2.800E-02	4.836E+01	5.367E+02	406.63
7	6.200E-02	-4.000E-03	-2.600E-02	4.838E+01	5.366E+02	406.63
8	6.200E-02	-4.000E-03	-1.400E-02	4.838E+01	5.369E+02	406.63
9	3.600E-02	-1.600E-02	-4.400E-02	4.837E+01	5.368E+02	406.63
10	4.800E-02	-8.000E-03	-1.000E-02	4.837E+01	5.369E+02	406.63
11	3.600E-02	1.200E-02	4.000E-03	4.836E+01	5.371E+02	406.63
12	-3.000E-02	-8.400E-02	-1.000E-01	4.857E+01	5.375E+02	406.63
13	1.600E-02	1.200E-02	-8.000E-03	4.853E+01	5.375E+02	406.63
14	6.600E-02	-6.000E-03	-2.000E-02	4.847E+01	5.375E+02	406.63
15	8.200E-02	3.000E-02	-1.400E-02	4.847E+01	5.375E+02	406.63
16	4.400E-02	-1.600E-02	-4.200E-02	4.845E+01	5.377E+02	406.63
17	5.400E-02	1.020E-02	-8.000E-03	4.850E+01	5.379E+02	406.63
18	7.600E-02	3.700E-02	1.400E-02	4.849E+01	5.379E+02	406.63
19	-4.000E-02	-9.400E-02	-1.120E-01	4.834E+01	5.384E+02	406.63
20	6.600E-02	6.000E-02	4.000E-02	4.833E+01	5.383E+02	406.63
21	-4.800E-02	-1.060E-01	-1.160E-01	4.836E+01	5.382E+02	406.63
22	3.000E-02	-3.000E-02	-6.000E-02	4.838E+01	5.382E+02	406.63
23	6.000E-02	-4.000E-03	-4.000E-03	4.837E+01	5.387E+02	406.63
24	2.400E-02	-1.800E-02	-5.200E-02	4.836E+01	5.390E+02	406.63
25	4.600E-02	0.000E+00	-6.000E-03	4.834E+01	5.390E+02	406.63
26	5.800E-02	-1.600E-02	-3.200E-02	4.834E+01	5.391E+02	406.63
27	[illegible]	-3.400E-02	-6.600E-02	4.836E+01	5.394E+02	406.63
28	5.200E-02	-4.000E-03	-6.000E-03	4.835E+01	5.393E+02	406.63
29	5.600E-02	-2.700E-02	-3.800E-02	4.831E+01	5.394E+02	406.63
30	7.800E-02	8.000E-03	-1.000E-02	4.824E+01	5.396E+02	406.63
31	4.600E-02	-2.400E-02	-4.400E-02	4.822E+01	5.395E+02	406.63

TABLE B8

REFERENCE BLADE REDUCED DATA FILE PRINTOUT--UPSTREAM

****
FILE   L-01MAY7CALC
****

SCAN	PRO POSIT	BETA	GAMMA	PHI	Xvel	Xref
1	0.00	4.331E-02	1.078E-01	-7.371E-03	1.103E-01	9.351E-02
2	.10	4.342E-02	1.047E-01	-8.104E-03	1.104E-01	9.340E-02
3	.20	4.331E-02	1.060E-01	-9.131E-03	1.103E-01	9.311E-02
4	.30	4.340E-02	1.072E-01	-9.773E-03	1.104E-01	9.375E-02
5	.40	4.362E-02	1.177E-01	-1.250E-02	1.106E-01	9.332E-02
6	.50	4.374E-02	1.190E-01	-1.623E-02	1.107E-01	9.359E-02
7	.60	4.397E-02	1.150E-01	-1.398E-02	1.110E-01	9.340E-02
8	.70	4.386E-02	1.189E-01	-1.615E-02	1.109E-01	9.330E-02
9	.80	4.393E-02	1.122E-01	-1.244E-02	1.110E-01	9.354E-02
10	.90	4.404E-02	1.145E-01	-1.372E-02	1.112E-01	9.348E-02
11	1.00	4.396E-02	1.133E-01	-1.306E-02	1.111E-01	9.338E-02
12	1.10	4.409E-02	1.084E-01	-1.034E-02	1.113E-01	9.373E-02
13	1.20	4.439E-02	1.069E-01	-9.447E-03	1.117E-01	9.358E-02
14	1.30	4.431E-02	1.041E-01	-7.896E-03	1.116E-01	9.353E-02
15	1.40	4.450E-02	9.982E-02	-5.544E-03	1.119E-01	9.350E-02
16	1.50	4.445E-02	1.014E-01	6.394E-03	1.119E-01	9.330E-02
17	1.60	4.488E-02	1.001E-01	-5.667E-03	1.124E-01	9.357E-02
18	1.70	4.472E-02	9.873E-02	-4.653E-03	1.123E-01	9.351E-02
19	1.80	4.472E-02	1.027E-01	-6.011E-03	1.122E-01	9.377E-02
20	1.90	4.477E-02	9.437E-02	-2.551E-03	1.124E-01	9.312E-02
21	2.00	4.497E-02	1.024E-01	-6.903E-03	1.125E-01	9.331E-02
22	2.10	4.470E-02	1.050E-01	-8.377E-03	1.121E-01	9.305E-02
23	2.20	4.444E-02	1.067E-01	-9.357E-03	1.118E-01	9.348E-02
24	2.30	4.449E-02	1.139E-01	-1.333E-02	1.118E-01	9.348E-02
25	2.40	4.442E-02	1.154E-01	-1.416E-02	1.116E-01	9.334E-02
26	2.50	4.437E-02	1.195E-01	-1.647E-02	1.115E-01	9.343E-02
27	2.60	4.452E-02	1.209E-01	-1.719E-02	1.118E-01	9.340E-02
28	2.70	4.460E-02	1.218E-01	-1.771E-02	1.118E-01	9.347E-02
29	2.80	4.470E-02	1.267E-01	-2.015E-02	1.119E-01	9.348E-02
30	2.90	4.443E-02	1.224E-01	-1.806E-02	1.116E-01	9.347E-02
31	3.00	4.472E-02	1.239E-01	-1.885E-02	1.119E-01	9.351E-02

****

SCAN	Vel	Vref	Q	Qref	MACH	YAW DEG
1	2.798E+02	2.377E+02	1.720E+01	1.255E+01	2.487E-01	4.856E+01
2	2.803E+02	2.370E+02	1.724E+01	1.253E+01	2.485E-01	4.856E+01
3	2.802E+02	2.364E+02	1.719E+01	1.249E+01	2.481E-01	4.854E+01
4	2.803E+02	2.366E+02	1.727E+01	1.248E+01	2.483E-01	4.855E+01
5	2.809E+02	2.370E+02	1.729E+01	1.250E+01	2.488E-01	4.846E+01
6	2.811E+02	2.377E+02	1.732E+01	1.258E+01	2.490E-01	4.841E+01
7	2.818E+02	2.372E+02	1.741E+01	1.254E+01	2.497E-01	4.843E+01
8	2.815E+02	2.370E+02	1.737E+01	1.250E+01	2.494E-01	4.843E+01
9	2.820E+02	2.376E+02	1.743E+01	1.256E+01	2.498E-01	4.842E+01
10	2.823E+02	2.374E+02	1.747E+01	1.255E+01	2.501E-01	4.842E+01
11	2.821E+02	2.372E+02	1.744E+01	1.252E+01	2.499E-01	4.841E+01
12	2.828E+02	2.368E+02	1.751E+01	1.249E+01	2.504E-01	4.857E+01
13	2.839E+02	2.378E+02	1.761E+01	1.257E+01	2.514E-01	4.850E+01
14	2.837E+02	2.377E+02	1.762E+01	1.256E+01	2.512E-01	4.852E+01
15	2.845E+02	2.378E+02	1.772E+01	1.257E+01	2.519E-01	4.852E+01
16	2.843E+02	2.371E+02	1.769E+01	1.250E+01	2.517E-01	4.850E+01
17	2.853E+02	2.379E+02	1.780E+01	1.257E+01	2.520E-01	4.855E+01
18	2.854E+02	2.377E+02	1.787E+01	1.255E+01	2.526E-01	4.854E+01
19	2.854E+02	2.377E+02	1.781E+01	1.249E+01	2.525E-01	4.839E+01
20	2.858E+02	2.368E+02	1.785E+01	1.245E+01	2.528E-01	4.838E+01
21	2.858E+02	2.373E+02	1.788E+01	1.250E+01	2.531E-01	4.841E+01

TABLE B8 (CONTINUED)

22	2.852E+02	2.382E+02	1.779E+01	1.259E+01	2.524E-01	4.843E+01
23	2.844E+02	2.378E+02	1.767E+01	1.255E+01	2.515E-01	4.842E+01
24	2.844E+02	2.379E+02	1.765E+01	1.255E+01	2.515E-01	4.841E+01
25	2.841E+02	2.375E+02	1.763E+01	1.251E+01	2.512E-01	4.839E+01
26	2.836E+02	2.378E+02	1.759E+01	1.253E+01	2.509E-01	4.839E+01
27	2.846E+02	2.378E+02	1.768E+01	1.252E+01	2.516E-01	4.841E+01
28	2.846E+02	2.379E+02	1.768E+01	1.254E+01	2.516E-01	4.840E+01
29	2.848E+02	2.380E+02	1.770E+01	1.255E+01	2.517E-01	4.838E+01
30	2.841E+02	2.379E+02	1.761E+01	1.254E+01	2.510E-01	4.829E+01
31	2.849E+02	2.381E+02	1.777E+01	1.755E+01	2.518E-01	4.827E+01

****

SCAN	Pref Pt/Qref	U	Ire
1	2.329E-01	1.009E+00	1.172E+00
2	2.283E-01	1.010E+00	1.175E+00
3	2.267E-01	1.009E+00	1.177E+00
4	2.241E-01	1.010E+00	1.177E+00
5	2.174E-01	1.010E+00	1.178E+00
6	2.179E-01	1.010E+00	1.176E+00
7	2.097E-01	1.010E+00	1.181E+00
8	2.087E-01	1.010E+00	1.181E+00
9	2.119E-01	1.010E+00	1.190E+00
10	2.077E-01	1.010E+00	1.182E+00
11	2.059E-01	1.010E+00	1.183E+00
12	2.063E-01	1.010E+00	1.187E+00
13	1.978E-01	1.010E+00	1.187E+00
14	1.966E-01	1.010E+00	1.187E+00
15	1.938E-01	1.010E+00	1.190E+00
16	1.920E-01	1.010E+00	1.192E+00
17	1.814E-01	1.010E+00	1.195E+00
18	1.871E-01	1.010E+00	1.194E+00
19	1.859E-01	1.010E+00	1.197E+00
20	1.76[illegible]	1.010E+00	1.200E+00
21	1.802E-01	1.010E+00	1.199E+00
22	1.852E-01	1.010E+00	1.191E+00
23	1.846E-01	1.010E+00	1.189E+00
24	1.854E-01	1.010E+00	1.189E+00
25	1.839E-01	1.010E+00	1.190E+00
26	1.871E-01	1.010E+00	1.187E+00
27	1.837E-01	1.010E+00	1.191E+00
28	1.775E-01	1.010E+00	1.190E+00
29	1.778E-01	1.010E+00	1.191E+00
30	1.823E-01	1.010E+00	1.188E+00
31	1.789E-01	1.010E+00	1.191E+00

****

ENSEMBLE AVERAGES

PTAVG	PAAVG	TEMPAVG	XREFAVG	VREFAVG	QREFAVG
1.767E+01	496.53E+00	537.82	9.342E-02	2.375E+02	1.253E+01
MUREF	TEMPSTATAVG				
1.228E-05	5.331E+07				

REYNOLDS NO
7.2691E+05

****

TABLE B9

REFERENCE BLADE REDUCED DATA FILE PRINTOUT--DOWNSTREAM

****

FILE U-01JUNCALC

****

****

SCAN	PRB POSIT	BETA	GAMMA	PHI	Xvel	Xref
1	-3.00	2.725E-02	6.991E-02	5.347E-03	8.626E-02	9.362E-02
2	-2.90	2.711E-02	7.275E-02	3.890E-03	8.604E-02	9.340E-02
3	-2.70	2.692E-02	7.184E-02	4.334E-03	8.575E-02	9.349E-02
4	-2.60	2.673E-02	7.328E-02	3.587E-03	8.544E-02	9.351E-02
5	-2.50	2.627E-02	7.625E-02	2.043E-03	8.470E-02	9.361E-02
6	-2.40	2.554E-02	7.661E-02	1.820E-03	8.353E-02	9.318E-02
7	-2.30	2.483E-02	7.344E-02	3.401E-03	8.238E-02	9.320E-02
8	-2.20	2.355E-02	7.754E-02	1.317E-03	8.028E-02	9.320E-02
9	-2.10	2.215E-02	8.341E-02	-1.638E-03	7.793E-02	9.332E-02
10	-2.00	2.044E-02	8.770E-02	-3.765E-03	7.496E-02	9.315E-02
11	-1.90	1.905E-02	8.460E-02	-2.107E-03	7.246E-02	9.327E-02
12	-1.80	1.782E-02	9.272E-02	-6.261E-03	7.014E-02	9.331E-02
13	-1.70	1.640E-02	8.851E-02	-4.075E-03	6.735E-02	9.306E-02
14	-1.60	1.552E-02	8.765E-02	-3.656E-03	6.557E-02	9.307E-02
15	-1.50	1.484E-02	9.438E-02	-7.224E-03	6.409E-02	9.320E-02
16	-1.40	1.493E-02	8.893E-02	-4.365E-03	6.431E-02	9.317E-02
17	-1.30	1.530E-02	8.422E-02	-1.880E-03	6.511E-02	9.315E-02
18	-1.20	1.619E-02	9.626E-02	-8.120E-03	6.691E-02	9.320E-02
19	-1.10	1.764E-02	8.795E-02	-3.786E-03	6.980E-02	9.324E-02
20	-1.00	1.936E-02	8.596E-02	-2.821E-03	7.303E-02	9.314E-02
21	-.90	2.099E-02	8.377E-02	-1.777E-03	7.593E-02	9.344E-02
22	-.80	2.254E-02	7.873E-02	7.331E-04	7.860E-02	9.312E-02
23	-.70	2.345E-02	7.643E-02	1.883E-03	8.012E-02	9.331E-02
24	-.60	2.421E-02	7.515E-02	2.525E-03	8.137E-02	9.337E-02
25	-.50	2.480E-02	7.390E-02	3.169E-03	8.234E-02	9.323E-02
26	-.40	2.510E-02	7.397E-02	3.142E-03	8.281E-02	9.316E-02
27	-.30	2.523E-02	7.659E-02	1.814E-03	8.304E-02	9.316E-02
28	-.20	2.538E-02	7.463E-02	2.814E-03	8.327E-02	9.299E-02
29	-.10	2.529E-02	7.450E-02	2.878E-03	8.314E-02	9.324E-02
30	0.00	2.539E-02	7.686E-02	1.686E-03	8.329E-02	9.297E-02
31	.10	2.540E-02	7.476E-02	2.751E-03	8.331E-02	9.331E-02
32	.20	2.540E-02	7.305E-02	3.621E-03	8.331E-02	9.313E-02
33	.30	2.536E-02	7.505E-02	2.600E-03	8.375E-02	9.317E-02
34	.40	2.529E-02	7.409E-02	2.681E-03	8.313E-02	9.316E-02
35	.50	2.493E-02	7.099E-02	4.651E-03	8.255E-02	9.327E-02
36	.55	2.439E-02	6.593E-02	7.71[illegible]E-03	8.167E-02	9.315E-02
37	.60	2.428E-02	7.335E-02	3.442E-03	8.149E-02	9.318E-02
38	.65	2.365E-02	7.677E-02	1.707E-03	8.045E-02	9.307E-02
39	.70	2.370E-02	7.416E-02	3.030E-03	8.054E-02	9.324E-02
40	.75	2.255E-02	7.591E-02	2.167E-03	7.861E-02	9.349E-02
41	.80	2.227E-02	7.557E-02	2.353E-03	7.815E-02	9.335E-02
42	.85	2.146E-02	8.119E-02	-4.807E-04	7.675E-02	9.290E-02
43	.90	2.069E-02	8.125E-02	-4.702E-04	7.542E-02	9.294E-02
44	.95	2.024E-02	8.239E-02	-1.032E-03	7.461E-02	9.330E-02
45	1.00	1.945E-02	8.604E-02	-2.866E-03	7.319E-02	9.336E-02
46	1.05	1.862E-02	8.584E-02	-2.727E-03	7.165E-02	9.297E-02
47	1.10	1.795E-02	8.423E-02	-1.877E-03	7.040E-02	9.307E-02
48	1.15	1.719E-02	9.197E-02	-5.860E-03	6.891E-02	9.302E-02
49	1.20	1.680E-02	9.410E-02	-6.977E-03	6.815E-02	9.331E-02
50	1.25	1.635E-02	9.322E-02	-6.530E-03	6.723E-02	9.332E-02
51	1.30	1.569E-02	9.685E-02	-8.452E-03	6.589E-02	9.308E-02
52	1.35	1.531E-02	9.202E-02	-5.948E-03	6.511E-02	9.307E-02
53	1.40	1.500E-02	9.299E-02	-6.482E-03	6.444E-02	9.323E-02
54	1.45	1.485E-02	9.626E-02	-8.200E-03	6.410E-02	9.326E-02
55	1.50	1.460E-02	9.295E-02	-6.495E-03	6.358E-02	9.319E-02
56	1.55	1.470E-02	9.590E-02	-8.030E-03	6.380E-02	9.321E-02
57	1.60	1.485E-02	9.429E-02	-7.174E-03	6.412E-02	9.322E-02
58	1.65	1.493E-02	9.929E-02	-9.784E-03	6.477E-02	9.298E-02

TABLE B9 (CONTINUED)

59	1.70	1.534E-02	9.282E-02	-6.365E-03	6.516E-02	9.306E-02
60	1.75	1.609E-02	9.657E-02	-8.284E-03	6.670E-02	9.297E-02
61	1.80	1.654E-02	9.621E-02	-8.082E-03	6.762E-02	9.303E-02
62	1.85	1.711E-02	9.640E-02	-[illegible].167E-03	6.874E-02	9.307E-02
63	1.90	1.783E-02	9.218E-02	-5.981E-03	7.014E-02	9.280E-02
64	1.95	1.893E-02	9.204E-02	-5.938E-03	7.223E-02	9.311E-02
65	2.00	1.984E-02	8.947E-02	-4.647E-03	7.389E-02	9.302E-02
66	2.05	2.070E-02	8.358E-02	-1.662E-03	7.543E-02	9.313E-02
67	2.10	2.153E-02	6.476E-02	-2.305E-03	7.687E-02	9.319E-02
68	2.15	2.251E-02	8.336E-02	-1.625E-03	7.853E-02	9.297E-02
69	2.20	2.319E-02	8.273E-02	-1.319E-03	7.968E-02	9.306E-02
70	2.25	2.389E-02	8.105E-02	-4.692E-04	8.084E-02	9.318E-02
71	2.30	2.422E-02	7.654E-02	1.820E-03	8.138E-02	9.3[illegible]9E-02
72	2.40	2.520E-02	7.653E-02	1.846E-03	8.298E-02	9.302E-02
73	2.50	2.594E-02	7.445E-02	2.935E-03	8.418E-02	9.297E-02
74	2.60	2.617E-02	7.489E-02	2.724E-03	8.454E-02	9.324E-02
75	2.70	2.636E-02	7.560E-02	2.382E-03	8.485E-02	9.326E-02
76	2.80	2.655E-02	7.486E-02	2.772E-03	8.516E-02	9.306E-02
77	2.90	2.655E-02	7.864E-02	8.512E-04	8.515E-02	9.310E-02
78	3.00	2.663E-02	8.146E-02	-5.699E-04	8.528E-02	9.308E-02

****

SCAN	Vel	Vref	Q	Qref	MACH	YAW DEG
1	2.188E+02	2.375E+02	1.060E+01	1.261E+01	1.936E-01	2.687E+00
2	2.183E+02	2.370E+02	1.063E+01	1.255E+01	1.931E-01	2.833E+00
3	2.175E+02	2.372E+02	1.055E+01	1.257E+01	1.924E-01	2.800E+00
4	2.167E+02	2.372E+02	1.048E+01	1.258E+01	1.917E-01	2.518E+00
5	2.147E+02	2.373E+02	1.029E+01	1.260E+01	1.901E-01	2.392E+00
6	2.117E+02	2.361E+02	1.001E+01	1.249E+01	1.874E-01	2.253E+00
7	2.088E+02	2.362E+02	9.733E+00	1.249E+01	1.848E-01	2.137E+00
8	2.034E[illegible]	2.362E+02	9.239E+00	1.249E+01	1.801E-01	2.029E+00
9	1.975E+02	2.365E+02	8.703E+00	1.253E+01	1.748E-01	1.755E+00
10	1.900E+02	2.361E+02	8.048E+00	1.248E+01	1.681E-01	1.672E+00
11	1.836E+02	2.363E+02	7.517E+00	1.251E+01	1.625E-01	1.598E+00
12	1.777E+02	2.364E+02	7.039E+00	1.252E+01	1.572E-01	1.609E+00
13	1.709E+02	2.362E+02	6.490E+00	1.246E+01	1.510E-01	1.586E+00
14	1.666E+02	2.364E+02	6.149E+00	1.246E+01	1.469E-01	1.858E+00
15	1.628E+02	2.368E+02	5.873E+00	1.249E+01	1.436E-01	2.135E+00
16	1.634E+02	2.367E+02	5.913E+00	1.248E+01	1.441E-01	2.537E+00
17	1.654E+02	2.366E+02	6.062E+00	1.248E+01	1.459E-01	2.656E+00
18	1.700E+02	2.368E+02	6.402E+00	1.249E+01	1.499E-01	2.904E+00
19	1.774E+02	2.369E+02	6.971E+00	1.250E+01	1.565E-01	3.177E+00
20	1.856E+02	2.367E+02	7.636E+00	1.248E+01	1.637E-01	3.301E+00
21	1.930E+02	2.375E+02	8.258E+00	1.256E+01	1.703E-01	3.282E+00
22	1.998E+02	2.367E+02	8.853E+00	1.247E+01	1.763E-01	3.176E+00
23	[illegible]036E+02	2.371E+02	9.202E+00	1.252E+01	1.797E-01	3.152E+00
24	2.069E+02	2.374E+02	9.496E+00	1.254E+01	1.826E-01	3.171E+00
25	2.094E+02	2.371E+02	9.724E+00	1.250E+01	1.847E-01	2.925E+00
26	2.106E+02	2.369E+02	9.838E+00	1.248E+01	1.858E-01	2.907E+00
27	2.112E+02	2.370E+02	9.891E+00	1.248E+01	1.863E-01	2.655E+00
28	2.118E+02	2.365E+02	9.948E+00	1.244E+01	1.868E-01	2.760E+00
29	2.115E+02	2.372E+02	9.916E+00	1.250E+01	1.865E-01	2.767E+00
30	2.119E+02	2.365E+02	9.953E+00	1.243E+01	1.869E-01	2.777E+00
31	2.119E+02	2.374E+02	9.956E+00	1.252E+01	1.869E-01	2.613E+00
32	2.120E+02	2.369E+02	9.958E+00	1.247E+01	1.869E-01	2.649E+00
33	2.118E+02	2.370E+02	9.947E+00	1.248E+01	1.868E-01	2.613E+00
34	2.115E+02	2.371E+02	9.915E+00	1.248E+01	1.865E-01	2.264E+00
35	2.100E+02	2.373E+02	9.777E+00	1.251E+01	1.852E-01	2.265E+00
36	2.078E+02	2.370E+02	9.567E+00	1.248E+01	1.832E 01	2.121E+00
37	2.073E+02	2.371E+02	9.523E+00	1.249E+01	1.828E-01	2.120E+00
38	2.047E+02	2.367E+02	9.281E+00	1.245E+01	1.805E-01	2.119E+00
39	2.050E+02	2.373E+02	9.301E+00	1.250E+01	1.807E-01	1.989E+00
40	2.000E+02	2.379E+02	8.850E+00	1.257E+01	1.763E-01	1.722E+00
41	1.980E+02	2.376E+02	8.754E+00	1.253E+01	1.753E-01	1.857E+00

41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42	1.954E+02	2.365E+02	8.441E+00	1.241E+01	1.721E-01	1.731E+00
43	1.920E+02	2.367E+02	8.148E+00	1.242E+01	1.691E-01	1.726E+00
44	1.900E+02	2.376E+02	7.974E+00	1.252E+01	1.673E-01	1.491E+00
45	1.864E+02	2.377E+02	7.671E+00	1.254E+01	1.641E-01	1.555E+00
46	1.825E+02	2.368E+02	7.349E+00	1.24[illegible]E+01	1.606E-01	1.307E+00
47	1.793E+02	2.371E+02	7.094E+00	1.246E+01	1.578E-01	1.337E+00
48	1.756E+02	2.370E+02	6.795E+00	1.245E+01	1.544E-01	1.473E+00
49	1.736E+02	2.377E+02	6.645E+00	1.252E+01	1.527E-01	1.483E+00
50	1.712E+02	2.377E+02	6.467E+00	1.253E+01	1.507E-01	1.520E+00
51	1.679E+02	2.371E+02	6.210E+00	1.246E+01	1.476E-01	1.592E+00
52	1.659E+02	2.371E+02	6.064E+00	1.246E+01	1.459E-01	1.574E+00
53	1.642E+02	2.375E+02	5.940E+00	1.250E+01	1.444E-01	1.764E+00
54	1.633E+02	2.376E+02	5.876E+00	1.251E+01	1.436E-01	1.832E+00
55	1.620E+02	2.374E+02	5.781E+00	1.249E+01	1.425E-01	2.047E+00
56	1.625E+02	2.374E+02	5.820E+00	1.250E+01	1.429E-01	2.108E+00
57	1.633E+02	2.375E+02	5.879E+00	1.250E+01	1.437E-01	2.244E+00
58	1.638E+02	2.369E+02	5.907E+00	1.243E+01	1.440E-01	2.303E+00
59	1.660E+02	2.371E+02	6.073E+00	1.246E+01	1.460E-01	2.636E+00
60	1.699E+02	2.369E+02	6.363E+00	1.243E+01	1.495E-01	2.904E+00
61	1.723E+02	2.370E+02	6.541E+00	1.245E+01	1.516E-01	3.007E+00
62	1.751E+02	2.371E+02	6.759E+00	1.246E+01	1.541E-01	3.156E+00
63	1.787E+02	2.364E+02	7.040E+00	1.238E+01	1.572E-01	3.134E+00
64	1.840E+02	2.372E+02	7.467E+00	1.247E+01	1.619E-01	3.321E+00
65	1.882E+02	2.370E+02	7.815E+00	1.245E+01	1.657E-01	3.298E+00
66	1.921E+02	2.372E+02	8.147E+00	1.2[illegible]E+01	1.691E-01	3.416E+00
67	1.958E+02	2.374E+02	8.464E+00	1.249E+01	1.724E-01	3.356E+00
68	2.000E+02	2.368E+02	8.837E+00	1.243E+01	1.762E-01	3.379E+00
69	2.029E+02	2.370E+02	9.098E+00	1.245E+01	1.787E-01	3.327E+00
70	2.059E+02	2.373E+02	9.368E+00	1.249E+01	1.814E-01	3.295E+00
71	2.072E+02	2.375E+02	9.496E+00	1.252E+01	1.826E-01	3.311E+00
72	2.113E+02	2.369E+02	9.876E+00	1.245E+01	1.862E-01	3.140E+00
73	2.14[illegible]E+02	2.368E+02	1.017E+01	1.243E+01	1.889E-01	3.155E+00
74	2.153E+02	2.375E+02	1.026E+01	1.250E+01	1.897E-01	3.036E+00
75	2.161E+02	2.375E+02	1.033E+01	1.251E+01	1.904E-01	3.027E+00
76	2.168E+02	2.370E+02	1.041E+01	1.246E+01	1.911E-01	2.862E+00
77	2.168E+02	2.371E+02	1.041E+01	1.247E+01	1.911E-01	2.859E+00
78	2.172E+02	2.370E+02	1.044E+01	1.246E+01	1.914E-01	2.878E+00

****

SCAN	Pref-Pt/Qref	U	Ire
1	1.778E-01	1.006E+00	9.248E-01
2	1.808E-01	1.006E+00	9.246E-01
3	1.869E-01	1.006E+00	9.205E-01
4	1.954E-01	1.006E+00	9.167E-01
5	2.136E-01	1.006E+00	9.076E-01
6	2.298E-01	1.005E+00	8.990E-01
7	2.560E-01	1.005E+00	8.860E-01
8	3.001E-01	1.005E+00	8.628E-01
9	3.478E-01	1.005E+00	8.359E-01
10	4.008E-01	1.004E+00	8.048E-01
11	4.457E-01	1.004E+00	7.765E-01
12	4.860E-01	1.004E+00	7.507E-01
13	5.268E-01	1.004E+00	7.224E-01
14	5.557E-01	1.003E+00	7.029E-01
15	5.790E-01	1.003E+00	6.858E-01
16	5.769E-01	1.003E+00	6.884E-01
17	5.661E-01	1.003E+00	6.972E-01
18	5.43[illegible]E-01	1.003E+00	7.163E-01
19	4.95[illegible]E-01	1.004E+00	7.475E-01
20	4.38[illegible]-01	1.004E+00	7.837E-01
21	3.906E-01	1.004E+00	8.177E-01
22	3.339E-01	1.005E+00	8.450E-01
23	3.036E-01	1.005E+00	8.601E-01
24	2.740E-01	1.005E+00	8.734E-01
25	2.578E-01	1.005E+00	8.853E-01

TABLE B9 (CONTINUED)

25	[illegible]	[illegible]	[illegible]
26	2.418E-01	1.005E+00	8.513E-01
27	2.376E-01	1.005E+00	8.938E-01
28	2.295E-01	1.005E+00	8.981E-01
29	2.335E-01	1.005E+00	8.942E-01
30	2.286E-01	1.005E+00	8.985E-01
31	2.346E-01	1.005E+00	8.953E-01
32	2.281E-01	1.005E+00	8.977E-01
33	2.328E-01	1.005E+00	8.961E-01
34	2.326E-01	1.005E+00	8.949E-01
35	2.406E-01	1.005E+00	8.875E-01
36	2.651E-01	1.005E+00	8.788E-01
37	2.684E-01	1.005E+00	8.765E-01
38	2.854E-01	1.005E+00	8.666E-01
39	2.895E-01	1.005E+00	8.654E-01
40	3.287E-01	1.005E+00	8.42[illegible]E-01
41	3.343E-01	1.005E+00	8.387E-01
42	3.566E-01	1.005E+00	8.269E-01
43	3.854E-01	1.004E+00	8.118E-01
44	4.040E-01	1.004E+00	7.998E-01
45	4.249E-01	1.004E+00	7.838E-01
46	4.545E-01	1.004E+00	7.701E-01
47	4.721E-01	1.004E+00	7.557E-01
48	4.961E-01	1.004E+00	7.398E-01
49	5.160E-01	1.004E+00	7.291E-01
50	5.269E-01	1.003E+00	7.192E-01
51	5.455E-01	1.003E+00	7.064E-01
52	5.536E-01	1.003E+00	6.981E-01
53	5.650E-01	1.003E+00	6.896E-01
54	5.760E-01	1.003E+00	6.856E-01
55	5.874E-01	1.003E+00	6.805E-01
56	5.787E-01	1.003E+00	6.876E-01
57	5.766E-01	1.003E+00	6.86[illegible]-01
58	5.747E-01	1.003E+00	6.895E-01
59	5.614E-01	1.003E+00	6.986E-01
60	5.370E-01	1.003E+00	7.159E-01
61	5.285E-01	1.004E+00	7.254E-01
62	5.118E-01	1.004E+00	7.373E-01
63	4.874E-01	1.004E+00	7.548E-01
64	4.562E-01	1.004E+00	7.750E-01
65	4.263E-01	1.004E+00	7.939E-01
66	3.984E-01	1.004E+00	8.099E-01
67	3.739E-01	1.005E+00	8.252E-01
68	3.368E-01	1.005E+00	8.456E-01
69	3.155E-01	1.005E+00	8.573E-01
70	2.956E-01	1.005E+00	8.690E-01
71	2.815E-01	1.005E+00	8.740E-01
72	2.455E-01	1.005E+00	8.943E-01
73	2.143E-01	1.005E+00	9.0[illegible]3E-01
74	2.116E-01	1.006E+00	9.095E-01
75	2.016E-01	1.006E+00	9.128E-01
76	1.937E-01	1.006E+00	9.187E-01
77	1.911E-01	1.006E+00	9.179E-01
78	1.903E-01	1.006E+00	9.194E-01

** ********************************

ENSEMBLE AVERAGES

PPAVG	PAAVG	TEMPAVG	XREFAVG	VREFAVG	QREFAVG
1.263E+01	407.37E+00	538.51	9.318E-02	2.370E+02	1.249E+01

MUREF	TEMPSTATAVG
1.229E-05	5.338E+02

REYNOLDS NO
4.8660E+05
****

TABLE B10

SLOTTED BLADE REDUCED DATA FILE PRINTOUT--DOWNSTREAM

****
FILE U-31MAYMCALC
****

****

SCAN	PRB POSIT	BETA	GAMMA	PHI	Xvel	Xref
1	-3.00	2.681E-02	6.655E-02	7.010E-03	8.556E-02	9.292E-02
2	-2.90	2.650E-02	7.112E-02	4.661E-03	8.507E-02	9.290E-02
3	-2.70	2.633E-02	7.524E-02	2.559E-03	8.480E-02	9.304E-02
4	-2.60	2.593E-02	7.273E-02	3.807E-03	8.416E-02	9.315E-02
5	-2.50	2.524E-02	7.610E-02	2.067E-03	8.305E-02	9.282E-02
6	-2.40	2.414E-02	7.350E-02	3.366E-03	8.125E-02	9.276E-02
7	-2.30	2.296E-02	7.382E-02	3.222E-03	7.930E-02	9.276E-02
8	-2.20	2.199E-02	7.930E-02	4.628E-04	7.767E-02	9.292E-02
9	-2.10	2.048E-02	8.413E-02	-1.935E-03	7.504E-02	9.287E-02
10	-2.00	1.919E-02	8.433E-02	-1.974E-03	7.272E-02	9.286E-02
11	-1.90	1.751E-02	8.348E-02	-1.473E-03	6.956E-02	9.276E-02
12	-1.80	1.654E-02	8.403E-02	-1.746E-03	6.766E-02	9.286E-02
13	-1.70	1.533E-02	8.657E-02	-3.156E-03	6.517E-02	9.287E-02
14	-1.60	1.485E-02	8.363E-02	-1.605E-03	6.416E-02	9.294E-02
15	-1.50	1.467E-02	8.733E-02	-3.551E-03	6.376E-02	9.292E-02
16	-1.40	1.489E-02	8.112E-02	-2.931E-04	6.426E-02	9.297E-02
17	-1.30	1.529E-02	7.835E-02	1.173E-03	6.511E-02	9.290E-02
18	-1.20	1.645E-02	8.306E-02	-1.246E-03	6.748E-02	9.287E-02
19	-1.10	1.765E-02	8.032E-02	1.592E-04	6.985E-02	9.282E-02
20	-1.00	1.922E-02	7.365E-02	3.518E-03	7.280E-02	9.305E-02
21	-.90	2.073E-02	7.516E-02	2.644E-03	7.550E-02	9.288E-02
22	-.90	2.214E-02	7.573E-02	2.275E-03	7.792E-02	9.283E-02
23	-.70	2.337E-02	7.600E-02	2.103E-03	7.998E-02	9.293E-02
24	-.60	2.407E-02	7.351E-02	3.359E-03	8.115E-02	9.294E-02
25	-.50	2.463E-02	7.297E-02	3.639E-03	8.206E-02	9.296E-02
26	-.40	2.514E-02	7.470E-02	2.774E-03	8.289E-02	9.290E-02
27	-.30	2.523E-02	7.443E-02	2.914E-03	8.303E-02	9.296E-02
28	-.20	2.529E-02	7.215E-02	4.070E-03	8.313E-02	9.309E-02
29	-.10	2.534E-02	7.240E-02	3.945E-03	8.320E-02	9.284E-02
30	0.00	2.514E-02	7.430E-02	2.975E-03	8.289E-02	9.300E-02
31	.10	2.531E-02	7.191E-02	4.194E-03	8.316E-02	9.308E-02
32	.20	2.539E-02	6.863E-02	5.861E-03	8.330E-02	9.307E-02
33	.30	2.543E-02	7.024E-02	5.049E-03	8.335E-02	9.304E-02
34	.40	2.540E-02	6.748E-02	6.449E-03	8.331E-02	9.314E-02
35	.50	2.528E-02	6.817E-02	6.091E-03	8.312E-02	9.333E-02
36	.55	2.516E-02	7.216E-02	4.060E-03	8.292E-02	9.285E-02
37	.60	2.510E-02	7.090E 02	4.657E-03	8.283E 02	9.324E-02
38	.65	2.499E-02	7.284E-02	3.714E-03	8.254E-02	9.341E-02
39	.70	2.464E-02	7.313E-02	3.558E-03	8.207E 02	9.332E-02
40	.75	2.439E-02	7.213E-02	4.061E-03	8.166E 02	9.324E-02
41	.80	2.397E-02	7.301E-02	3.210E 03	8.098E-02	9.340E-02
42	.85	2.328E-02	7.523E-02	2.495E-03	7.984E-02	9.333E-02
43	.90	2.273E-02	7.795E-02	1.124E-03	7.892E-02	9.312E 02
44	.95	2.229E-02	8.124E-02	-5.406E-04	7.817E-02	9.330E-02
45	1.00	2.146E-02	7.569E-02	2.372E 03	7.677E-02	9.319E-02
46	1.05	2.083E-02	8.149E-02	-6.019E-04	7.565E-02	9.346E-02
47	1.10	2.021E-02	8.765E-02	-3.728E-03	7.455E-02	9.309E-02
49	1.15	1.941E-02	8.981E-02	-4.805E-03	7.312E-02	9.337E-02
49	1.20	1.824E-02	8.699E-02	-3.302E-03	7.094E-02	9.311E-02
50	1.25	1.78[illegible]E-02	9.583E 02	-7.873E-03	7.022E-02	9.331E-02
51	1.30	1.693E-02	1.021E-01	-1.114E-02	6.837E-02	9.334E-02
52	1.35	1.632E-02	1.010E-01	-1.056E-02	6.715E-02	9.337E-02
53	1.40	1.613E-02	9.674E-02	-8.371E-03	6.678E-02	9.334E 02
54	1.45	1.590E-02	1.024E-01	-1.134E-02	6.630E-02	9.345E-02
55	1.50	1.542E-02	9.939E-02	-9.795E-03	6.530E-02	9.309E-02
56	1.55	1.551E-02	1.022E-01	-1.125E-02	6.549E-02	9.366E-02
57	1.60	1.547E-02	1.003E-01	-1.027E-02	6.540E-02	9.335E-02
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE B10 (CONTINUED)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
59	1.70	1.595E-02	9.936E-02	-9.748E-03	6.641E-02	9.328E-02
60	1.75	1.632E-02	1.027E-01	-1.148E-02	6.716E-02	9.327E-02
61	1.80	1.678E-02	1.010E-01	-1.059E-02	6.807E-02	9.315E-02
62	1.85	1.754E-02	1.016E-01	-1.085E-02	6.957E-02	9.338E-02
63	1.90	1.834E-02	1.023E-01	-1.125E-02	7.109E-02	9.313E-02
64	1.95	1.907E-02	9.755E-02	-8.782E-03	7.248E-02	9.337E-02
65	2.00	2.005E-02	9.249E-02	-6.202E-03	7.426E-02	9.328E-02
66	2.05	2.111E-02	8.959E-02	-4.757E-03	7.613E-02	9.320E-02
67	2.10	2.199E-02	9.116E-02	-5.586E-03	7.766E-02	9.344E-02
68	2.15	2.277E-02	9.073E-02	-5.382E-03	7.898E-02	9.331E-02
69	2.20	2.371E-02	8.767E-02	-3.835E-03	8.054E-02	9.340E-02
70	2.25	2.438E-02	8.935E-02	-4.680E-03	8.164E-02	9.311E-02
71	2.30	2.496E-02	9.087E-02	-5.437E-03	8.258E-02	9.336E-02
72	2.40	2.577E-02	9.016E-02	-5.035E-03	8.390E-02	9.333E-02
73	2.50	2.617E-02	8.656E-02	-3.188E-03	8.454E-02	9.340E-02
74	2.60	2.649E-02	8.928E-02	-4.543E-03	8.505E-02	9.348E-02
75	2.70	2.662E-02	9.044E-02	-5.121E-03	8.525E-02	9.372E-02
76	2.80	2.662E-02	9.152E-02	-5.668E-03	8.525E-02	9.341E-02
77	2.90	2.669E-02	8.954E 02	-4.706E-03	8.537E-02	9.360E-02
78	3.00	2.672E-02	8.939E-02	-4.581E-03	8.541E-02	9.352E-02

****

SCAN	Vel	Vref	Q	Qref	MACH	YAW DEG
1	2.178E+02	2.365E+02	1.049E+01	1.240E+01	1.920E-01	3.033E+00
2	2.165E+02	2.364E+02	1.037E+01	1.233E+01	1.909E-01	2.919E+00
3	2.158E+02	2.368E+02	1.031E+01	1.243E+01	1.903E-01	2.893E+00
4	2.142E+02	2.371E+02	1.015E+01	1.246E+01	1.889E-01	2.783E+00
5	2.114E+02	2.363E+02	9.882E+00	1.237E+01	1.864E-01	2.504E+00
6	2.069E+02	2.362E+02	9.455E+00	1.236E+01	1.823E-01	2.393E+00
7	2.020E+02	2.362E+02	9.000E+00	1.236E+01	1.779E-01	2.230E+00
8	1.978E+02	2.366E+02	8.633E+00	1.240E+01	1.742E-01	1.976E+00
9	1.911E+02	2.365E+02	8.052E+00	1.239E+01	1.683E-01	1.957E+00
10	1.852E+02	2.365E+02	7.561E+00	1.238E+01	1.630E-01	1.826E+00
11	1.771E+02	2.362E+02	6.914E+00	1.236E+01	1.559E-01	1.717E+00
12	1.723E+02	2.365E+02	6.541E+00	1.238E+01	1.516E-01	1.850E+00
13	1.660E+02	2.366E+02	6.066E+00	1.239E+01	1.460E-01	1.972E+00
14	1.634E+02	2.367E+02	5.879E+00	1.241E+01	1.438E-01	2.220E+00
15	1.624E+02	2.367E+02	5.805E+00	1.240E+01	1.429E-01	2.444E+00
16	1.637E+02	2.368E+02	5.897E+00	1.241E+01	1.440E-01	2.896E+00
17	1.653E+02	2.367E+02	6.054E+00	1.240E+01	1.459E-01	3.139E+00
18	1.719E+02	2.366E+02	6.503E+00	1.239E+01	1.512E-01	3.264E+00
19	1.780E+02	2.365E+02	6.971E+00	1.237E+01	1.566E-01	3.369E+00
20	1.855E+02	2.371E+02	7.576E+00	1.244E+01	1.632E-01	3.611E+00
21	1.924E+02	2.367E+02	8.152E+00	1.239E+01	1.693E-01	3.492E+00
22	1.986E+02	2.366E+02	8.688E+00	1.238E+01	1.748E-01	3.374E+00
23	2.038E+02	2.368E+02	9.157E+00	1.240E+01	1.794E-01	3.358E+00
24	2.069E+02	2.369E+02	9.429E+00	1.241E+01	1.821E-01	3.153E+00
25	2.091E+02	2.369E+02	9.645E+00	1.241E+01	1.841E-01	3.120E+00
26	2.112E+02	2.367E+02	9.842E+00	1.240E+01	1.860E-01	2.984E+00
27	2.116E+02	2.369E+02	9.877E+00	1.241E+01	1.863E-01	2.856E+00
28	2.118E+02	2.371E+02	9.901E+00	1.244E+01	1.865E-01	2.731E+00
29	2.120E+02	2.366E+02	9.918E+00	1.238E+01	1.867E-01	2.767E+00
30	2.113E+02	2.370E+02	9.844E+00	1.242E+01	1.860E-01	2.717E+00
31	2.119E+02	2.372E+02	9.908E+00	1.245E+01	1.866E-01	2.828E+00
32	2.122E+02	2.370E+02	9.942E+00	1.243E+01	1.869E-01	2.833E+00
33	2.124E+02	2.371E+02	9.955E+00	1.243E+01	1.870E-01	2.711E+00
34	2.123E+02	2.373E+02	9.945E+00	1.246E+01	1.869E-01	2.576E+00
35	2.118E+02	2.378E+02	9.900E+00	1.251E+01	1.865E-01	2.330E+00
36	2.113E+02	2.365E+02	9.849E+00	1.239E+01	1.860E-01	2.331E+00
37	2.110E+02	2.376E+02	9.828E+00	1.249E+01	1.858E-01	2.262E+00
38	2.106E+02	2.380E+02	9.786E+00	1.253E+01	1.854E-01	2.174E+00
39	2.091E+02	2.377E+02	9.649E+00	1.251E+01	1.841E-01	2.063E+00
40	2.080E+02	2.375E+02	9.552E+00	1.249E+01	1.832E-01	1.948E+00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE B10 (CONTINUED)

41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42	2.034E+02	2.378E+02	9.126E+00	1.251E+01	1.791E-01	1.848E+00
43	2.011E+02	2.372E+02	8.914E+00	1.246E+01	1.770E-01	1.657E+00
44	1.992E+02	2.377E+02	8.746E+00	1.250E+01	1.753E-01	1.666E+00
45	1.956E+02	2.375E+02	8.431E+00	1.247E+01	1.722E-01	1.641E+00
46	1.928E+02	2.381E+02	8.190E+00	1.255E+01	1.697E-01	1.649E+00
47	1.899E+02	2.372E+02	7.949E+00	1.245E+01	1.672E-01	1.539E+00
48	1.862E+02	2.378E+02	7.645E+00	1.252E+01	1.639E-01	1.541E+00
49	1.807E+02	2.371E+02	7.193E+00	1.245E+01	1.590E-01	1.498E+00
50	1.789E+02	2.377E+02	7.048E+00	1.251E+01	1.574E-01	1.685E+00
51	1.741E+02	2.377E+02	6.680E+00	1.251E+01	1.532E-01	1.656E+00
52	1.710E+02	2.378E+02	6.442E+00	1.252E+01	1.505E-01	1.641E+00
53	1.701E+02	2.377E+02	6.371E+00	1.252E+01	1.497E-01	1.793E+00
54	1.689E+02	2.381E+02	6.279E+00	1.255E+01	1.486E-01	1.796E+00
55	1.664E+02	2.371E+02	6.090E+00	1.245E+01	1.463E-01	2.159E+00
56	1.668E+02	2.386E+02	6.128E+00	1.260E+01	1.468E-01	2.057E+00
57	1.666E+02	2.377E+02	6.110E+00	1.252E+01	1.466E-01	2.233E+00
58	1.672E+02	2.376E+02	6.155E+00	1.251E+01	1.471E-01	2.421E+00
59	1.691E+02	2.376E+02	6.299E+00	1.250E+01	1.488E-01	2.690E+00
60	1.710E+02	2.375E+02	6.441E+00	1.249E+01	1.505E-01	2.837E+00
61	1.734E+02	2.372E+02	6.620E+00	1.246E+01	1.526E-01	2.942E+00
62	1.771E+02	2.378E+02	6.915E+00	1.253E+01	1.559E-01	3.073E+00
63	1.811E+02	2.372E+02	7.222E+00	1.246E+01	1.594E-01	3.218E+00
64	1.846E+02	2.378E+02	7.509E+00	1.252E+01	1.625E-01	3.356E+00
65	1.891E+02	2.375E+02	7.884E+00	1.250E+01	1.665E-01	3.479E+00
66	1.939E+02	2.373E+02	8.289E+00	1.249E+01	1.707E-01	3.592E+00
67	1.978E+02	2.379E+02	8.628E+00	1.254E+01	1.742E-01	3.528E+00
68	2.011E+02	2.376E+02	8.925E+00	1.251E+01	1.772E-01	3.528E+00
69	2.051E+02	2.379E+02	9.285E+00	1.253E+01	1.807E-01	3.492E+00
70	2.080E+02	2.372E+02	9.542E+00	1.245E+01	1.832E-01	3.483E+00
71	2.104E+02	2.378E+02	9.767E+00	1.252E+01	1.853E-01	3.344E+00
72	2.137E+02	2.377E+02	1.009E+01	1.251E+01	1.893E-01	3.359E+00
73	2.153E+02	2.379E+02	1.024E+01	1.253E+01	1.897E-01	3.236E+00
74	[illegible]	2.381E+02	1.037E+01	1.255E+01	1.909E-01	3.242E+00
75	2.171E+02	2.387E+02	1.042E+01	1.262E+01	1.913E-01	3.072E+00
76	2.171E+02	2.379E+02	1.042E+01	1.253E+01	1.913E-01	3.121E+00
77	2.175E+02	2.384E+02	1.045E+01	1.259E+01	1.916E-01	3.086E+00
78	2.176E+02	2.382E+02	1.045E+01	1.256E+01	1.917E-01	3.078E+00

••

SCAN	Pref-Pt/Qref	U	Ire
1	1.875E-01	1.006E+00	9.239E-01
2	1.902E-01	1.006E+00	9.190E-01
3	1.996E-01	1.006E+00	9.145E-01
4	2.131E-01	1.005E+00	9.063E-01
5	2.331E-01	1.005E+00	8.972E-01
6	2.698E-01	1.005E+00	8.779E-01
7	3.126E-01	1.005E+00	8.560E-01
8	3.405E-01	1.005E+00	8.357E-01
9	3.975E-01	1.004E+00	8.080E-01
10	4.344E-01	1.004E+00	7.828E-01
11	4.901E-01	1.004E+00	7.489E-01
12	5.184E-01	1.004E+00	7.274E-01
13	5.598E-01	1.003E+00	7.001E-01
14	5.768E-01	1.003E+00	6.896E-01
15	5.814E-01	1.003E+00	6.843E-01
16	5.750E-01	1.003E+00	6.894E-01
17	5.621E-01	1.003E+00	6.991E-01
18	5.327E-01	1.004E+00	7.250E-01
19	4.895E-01	1.004E+00	7.515E-01
20	4.412E-01	1.004E+00	7.819E-01
21	3.895E-01	1.004E+00	8.130E-01
22	3.444E-01	1.005E+00	8.401E-01
23	3.034E-01	1.005E+00	8.620E-01
24	2.797E-01	1.005E+00	8.749E-01
25	2.578E-01	1.005E+00	8.848E-01

TABLE B10 (CONTINUED)

26	2.376E-01	1.005E+00	8.946E-01
27	2.365E-01	1.005E+00	8.956E-01
28	2.356E-01	1.005E+00	8.956E-01
29	2.305E-01	1.005E+00	8.997E-01
30	2.338E-01	1.005E+00	8.938E-01
31	2.327E-01	1.005E+00	8.959E-01
32	2.276E-01	1.005E+00	8.981E-01
33	2.254E-01	1.005E+00	8.985E-01
34	2.263E-01	1.005E+00	8.971E-01
35	2.326E-01	1.005E+00	8.932E-01
36	2.358E-01	1.005E+00	8.954E-01
37	2.395E-01	1.005E+00	8.900E-01
38	2.439E-01	1.005E+00	8.872E-01
39	2.584E-01	1.005E+00	8.816E-01
40	2.659E-01	1.005E+00	8.779E-01
41	2.803E-01	1.005E+00	8.689E-01
42	3.034E-01	1.005E+00	8.569E-01
43	3.237E-01	1.005E+00	8.486E-01
44	3.344E-01	1.005E+00	8.388E-01
45	3.659E-01	1.005E+00	8.243E-01
46	3.846E-01	1.004E+00	8.099E-01
47	4.072E-01	1.004E+00	8.009E-01
48	4.312E-01	1.004E+00	7.828E-01
49	4.702E-01	1.004E+00	7.612E-01
50	4.807E-01	1.004E+00	7.517E-01
51	5.119E-01	1.004E+00	7.313E-01
52	5.307E-01	1.003E+00	7.178E-01
53	5.340E-01	1.003E+00	7.140E-01
54	5.415E-01	1.003E+00	7.080E-01
55	5.591E-01	1.003E+00	6.939E-01
56	5.548E-01	1.003E+00	6.977E-01
57	5.560E-01	1.003E+00	6.990E-01
58	5.5[illegible]E-01	1.003E+00	7.019E-01
59	5.48[illegible]E-01	1.003E+00	7.103E-01
60	5.394E-01	1.003E+00	7.195E-01
61	5.217E-01	1.004E+00	7.294E-01
62	5.007E-01	1.004E+00	7.439E-01
63	4.778E-01	1.004E+00	7.624E-01
64	4.545E-01	1.004E+00	7.756E-01
65	4.249E-01	1.004E+00	7.957E-01
66	3.902E-01	1.004E+00	8.163E-01
67	3.626E-01	1.005E+00	8.316E-01
68	3.360E-01	1.005E+00	8.472E-01
69	3.054E-01	1.005E+00	8.636E-01
70	2.785E-01	1.005E+00	8.785E-01
71	2.604E-01	1.005E+00	8.855E-01
72	2.316E-01	1.005E+00	9.014E-01
73	2.176E-01	1.006E+00	9.078E-01
74	2.073E-01	1.006E+00	9.127E-01
75	2.024E-01	1.006E+00	9.127E-01
76	1.974E-01	1.006E+00	9.158E-01
77	1.956E-01	1.006E+00	9.152E-01
78	1.969E-01	1.006E+00	9.164E-01

ENSEMBLE AVERAGES

PRAVG	FAAVG	TEMPAVG	XREFAVG	VREFAVG	QREFAVG
1.260E+01	406.83E+00	540.02	9.315E-02	2.373E+02	1.246E+01

MUREF	TEMPSTATAVG
1.232E-05	5.353E+02

REYNOLDS NO

4.9150E+05

TABLE B11

BLADE COEFFICIENT OF PRESSURE SCALED DATA FILE PRINTOUT

****
BLADE SCALED DATA FILE   B-17APRSCL
****

PROBE DATA ASSOCIATED WITH THE BLADE DATA IS CONTAINED
IN FILE: U-17APR7SCL
SCAN: 49

SCANIVALVE PORT	PRESS (INCHES H2o)
1	2.000E-02
2	1.255E+01
3	1.322E+01
4	-3.662E+00
5	-1.100E+00
6	3.300E-01
7	9.380E-01
8	1.092E+00
9	9.120E-01
10	7.100E-01
11	7.260E-01
12	7.760E-01
13	1.046E+00
14	1.882E+00
15	2.478E+00
16	2.278E+00
17	1.460E+00
18	1.768E+00
19	2.448E+00
20	3.998E+00
21	4.880E+00
22	7.302E+00
23	-1.825E+01
24	-3.427E+01
25	-3.382E+01
26	-3.111E+01
27	-2.435E+01
28	-1.881E+01
29	-1.495E+01
30	-1.333E+01
31	-1.143E+01
32	-9.050E+00
33	-7.350E+00
34	-6.036E+00
35	-5.020E+00
36	-4.358E+00
37	-3.970E+00
38	-3.696E+00
39	-3.428E+00
40	-3.336E+00
41	-3.168E+00
42	-3.104E+00
43	9.600E-01
44	-9.956E+00
45	-3.514E+00
46	1.728E+00
47	1.142E+00
48	-2.886E+00

TABLE B12

BLADE COEFFICIENT OF PRESSURE REDUCED DATA FILE PRINTOUT

```
*************************************
BLADE CP FILE        B-29MARICALC
******************************************************************************
```

SCANIVALVE PORT	MASS AVERAGED COEFFICIENT OF PRESSURE
4	2.431E-01
5	3.733E-01
6	4.484E-01
7	4.777E-01
8	4.877E-01
9	4.829E-01
10	4.675E-01
11	4.772E-01
12	4.683E-01
13	4.845E-01
14	5.283E-01
15	5.610E-01
16	5.512E-01
17	5.064E-01
18	5.180E-01
19	5.530E-01
20	6.397E-01
21	6.831E-01
22	8.171E-01
23	-5.066E-01
24	-1.384E+00
25	-1.347E+00
26	-1.205E+00
27	-8.638E-01
28	-5.532E-01
29	-3.557E-01
30	-2.787E-01
31	-1.816E-01
32	-5.412E-02
33	4.036E-02
34	1.087E-01
35	1.633E-01
36	1.987E-01
37	2.250E-01
39	2.341E-01
39	2.482E-01
40	2.551E-01
41	2.655E-01
42	2.688E-01
43	7.788E-01
44	-9.269E-02
45	2.444E-01
46	5.210E-01
47	4.891E-01
48	2.805E-01

B.7 IMPROVEMENTS

Improvement in the method of obtaining probe survey data can be made by changing the three programs involved. Changes will make data acquisition more efficient, reduce the chance of erroneous entries and provide more accurate data. Recommendations include:

1. Classick's [Ref. 6] recommendation on DVM error correction is reiterated here.
2. Dynamically size the arrays in "CALC." ("LOSS and "ACQUIRE" have been dynamically sized in data files and arrays.)
3. Establish data files to include survey scan number and probe position to be used in flow field mapping.
4. Convert the use of "1" and "2" in previous programs to "l" and "u" for upstream and downstream positions. This would make program flow and conversion easier.
5. Do not combine "CALC" and "LOSS" as recommended by Classick. Combination would require repetition of "LOSS" in "CALC" for mass-averaged and mixed-out losses.

B8. SUMMARY OF PROGRAM STEPS

All commands except RETURN are executed by pressing the soft keys f1-f8 corresponding to the labels appearing at the bottom of the screen.

The following is a summary of program steps:

1. DVM, SCANNER and Scanivalve controller--ON
2. Disc Drive--ON
3. Disc Drive Amber lights--Extinguished
4. Computer, Monitor and Printer--ON
5. LOAD "/CLASSICK/PROGS/ACQUIRE"

6. RETURN

7. Press RUN

8. Type raw data file name for probe survey without quotation marks.

9. RETURN

10. Type scaled data file name for probe survey without quotation marks.

11. RETURN

12. Type atmospheric pressure in inches Hg.

13. RETURN

14. Press ONE PROBE or TWO PROBES

15. Type scan number, probe position. For two probe option, type scan number, lower probe position, upper probe position.

16. RETURN

17. Press REPEAT or RECORD

    [REPEAT returns prompt for scan number and position of data point to be repeated. RECORD stores data to the file.]

18. Press GO ON or END PRB DATA

    [GO ON returns prompt for next scan number and probe position. END PRB DATA terminates probe data collection.]

19. Press GO ON or COLLECT

    [GO ON by passes instrumented blade data collection and returns print option prompts (Step 20). COLLECT returns prompt for instrumented blade raw data file.]

    a. Type raw blade data file name

    b. RETURN

    c. Type scaled blade data file name

    d. RETURN

e. Press REPEAT or RECORD

[REPEAT repeats the blade pressure scan, RECORD stores data to the file.]

20. Follow the print option prompts

<u>Note that this is the only time to obtain a hard copy of the raw and scaled probe and blade data</u>.

21. Press GO ON or CALC

a. GO ON terminates "ACQUIRE." Note that "CALC" can be executed later by the commands:

1. LOAD "/CLASSICK/PROGS/CALC"

2. Press RUN, loads and executes "CALC"

b. Proceed at Step 22

22. Type the scaled probe data file name created in "ACQUIRE."

23. RETURN

24. Type the probe calibration coefficient file for X (velocity).

Note that for this work MIKEC3 is the X file.

25. RETURN

26. Type the probe calibration coefficient file for Phi (pitch).

Note that for this work MIKEC2 is the Phi file.

27. RETURN

28. Press ONE PROBE or TWO PROBES

[TWO PROBES will prompt the user for the upper probe calibration coefficient files for X and Phi]

29. Type the file name for the data to be reduced from the scaled data file. For two probes, a second reduced file name is required.

30. RETURN

31. Type in the probe block to vertical angle.

32. RETURN

    Note that this angle was 40.4 degrees for this work.

33. Type in the low limit scan # for the Reynolds number integration.

34. RETURN

35. Type in the high limit scan # for the Reynolds number integration.

36. RETURN

37. Press REDUCE DATA after amber light quits blinking.

38. Press GO ON or BLADE CP'S

    [GO ON returns prompt to load "LOSS" (Step 39), BLADE CP'S prompts for scaled blade data file]

    a. Type blade scaled data file name

    b. RETURN

    c. Type the file name for the data to be reduced from the scaled data file

    d. RETURN

    e. Type scan number associated with lower limit of integration of probe lower blade-to-blade survey

    f. RETURN

    g. Type scan number associated with height limit of integration of probe lower blade-to-blade survey.

    h. RETURN

    i. Press BLADE DATA after amber light quits blinking

39. Press GO ON or LOSS

    a. GO ON terminates "CALC" and would be the choice if only one of the survey pairs had been conducted. Note that "LOSS" can be executed later by the commands:

1. LOAD "/CLASSICK/PROGS/LOSS"

2. Press RUN, loads and executes "LOSS"

b. Proceed at Step 36

c. Note that "LOSS" requires upper and lower probe blade-to-blade reduced data file names.

40. Type the lower probe blade-to-blade survey reduced data file name.

41. RETURN

42. Type the lower probe survey maximum scan number.

43. RETURN

44. Type the upper probe blade-to-blade survey reduced data file name.

45. RETURN

46. Type the upper probe survey maximum scan number.

47. RETURN

48. Type the scan number corresponding to the lower limit of integration for the lower probe survey.

49. RETURN

50. Type the scan number corresponding to the upper limit of integration for the lower probe survey.

51. RETURN

52. Type the scan number corresponding to the lower limit of integration for the upper probe survey.

53. RETURN

54. Type the scan number corresponding to the upper limit of integration for the upper probe survey.

55. RETURN

[Note that integration interval for both upper and lower probes must be exactly equal even though the scan number entries may not be the same]

56. Program "LOSS" terminates after mass averaged and mixed-out flow conditions and losses have been calculated.

57. Information from loss is automatically printed out.

TABLE B13

ACQUIRE PROGRAM LISTING

```
10   !PROGRAM ACQUIRE
11   !THIS PROGRAM ACQUIRES DATA FROM 5-HOLE PROBE SURVEYS AND PRESSURE
12   !DISTRIBUTION FROM AN INSTRUMENTED BLADE. SEE CLASSICK M.S. THESIS
13   !SEPT 89 FOR PROGRAM DESCRIPTION AND DETAILS.
52   !******************** DIMENSION ARRAYS ****************************
53   OPTION BASE 1              !BASE OF ARRAY WILL BE ONE INSEAD OF ZERO
54   DIM Rawdat(1,106)          !THIS ARRAY WILL ACCOMODATE BOTH 48 PORT
55                              !SCANIVALVES AND 10 CHANNELS FROM THE SCANNER
56   DIM Scaled(1,106)          !ARRAY USED IN PRINTING PROBE & CASCADE PRSSURES
57                              !TO SCREEN
59   DIM Prntdata(1,48)         !ARRAY USED IN PRINTING BLADE PRESSURES TO SCREEN
60   DIM Prntdatb(1,48)
61   MAT Prntdata= (0)          !INITIALLY FILLS ARRAY WITH ZEROS-IF ENTIRE ARRAY
62                              !IS NOT FILLED WITH DATA, THEN REMAINDER OF ARRAY
63                              !WILL CONTAIN ZEROS.
65   MAT Prntdatb= (0)
66   !******************** VARIABLES ***********************************
67   Oport=1                    !DESIRED PORT. IT IS DESIRED THAT THE SCANIVALVE
68                              !BEGIN AT PORT 1.
70   Hport=14                   !HIGH PORT. LAST PORT ON THE SCANIVALVE THAT IS
71                              !OF INTEREST.
73   Oporta=1                   !SAME AS ABOVE EXCEPT IT PERTAINS TO SCANIVALVE
74                              !RESERVED FOR INSTRUMENTED BLADE SURVEY.
76   Hporta=48                  !ALL PORT USED ON THE BLADE SURVEY
77   Oportb=1                   !IN TWO PROBE SURVEYS, MORE PORTS ARE USED-THE
78                              !DESIRED PORT IS STILL 1.
80   Hportb=19                  !LAST PORT OF INTEREST FOR TWO PROBE SURVEYS.
81   Scntempch=10               !SCANNER CHANNEL ASSIGNED TO THERMOCOUPLE
82   Scnyawchn=74               ! "        "        "        " YAW TRANSDUCER.
83   Scnyawchnl=74              ! "        "        "        " LOWER PROBE YAW
84                              !TRANSDUCER FOR TWO PROBE SURVEYS.
86   Scnyawchnu=21  17           SCANNER CHANNEL ASSIGNED TO UPPER PROBE YAW
87                              !TRANSDUCER FOR TWO-PROBE SURVEYS.
89   Scnva=1                    !SCANIVALVE USED FOR INSTRUMENTED BLADE.
90   Scnvb=2                    ! "          "  "  PROBE & CASCADE PRESSURES.
91   Scn=709                    !SCANNER BUS ADDRESS
92   Svc=707                    !SCANIVALVE CONTROLLER BUS ADDRESS (HG-78K)
93   Dvm=722                    !DIGITAL VOLTMETER BUS ADDRESS
94   Scnrdsvc=1                 !SCANNER CHANNEL ASSIGNED TO READ SCANIVALVE
95                              !CONTROLLER (SCANIVALVE READ IS THE ONE FOR
96                              !PROBE AND CASCADE PRESSURES.)
98   Scnrdsvca=0                !SAME AS ABOVE EXCEPT THE SCANIVALVE READ IS FOR
99                              !THE INSTRUMENTED BLADE PRESSURES
101  Scnrdsvcb=1                !SAME AS ABOVE EXCEPT SCANIVALVE READ IS THE
102                             !ONE FOR PROBE & CASCADE PRESSURES WHEN 2-PROBE
103                             !OPTION IS SELECTED.
105  Scnstpsvca=40              !SCANNER CHANNEL ASSIGNED TO STEP SCANIVALVE A
106  Scnstpsvcb=41              ! "      "       "    "   "     "        B
107  Scnhmsvca=45               !SCANNER CHANNEL ASSIGNED TO HOME SCANIVALVE A
108  Scnhmsvcb=45               ! "      "       "    "   "     "        B
109  Maxdif=.000050             !ERROR TRAP FOR SPURIOUS DVM READINGS.
110  Prnter=701                 !BUS ADDRESS FOR PRINTER
111  Scren=1                    !BUS ADDRESS FOR MONITOR
112  LOADSUB ALL FROM "/CLASSICK/ROUTINES/SUBACQUIRE"
113  MASS STORAGE IS "/CLASSICK/DATA"  !ALLOWS RAW DATA FILE NAME TO BE ENTERED
114                                    !AT THE PROMPT WITHOUT PATHNAME
116  PRINT "**********************************************************"
117  PRINT ""
118  PRINT "NAME FILE FOR THE RAW DATA TO BE COLLECTED FROM THE PROBE(S)"
119  INPUT Rawfile$
123  CREATE BDAT Rawfile$,100,848 !RAWFILE$ IS A STRING VARIABLE ASSIGNED
124                               !THE RAWFILE NAME TO BE ENTERED AT THE PROMPT
125                               !THIS FILE IS 100 RECORDS (ENOUGH FOR 100 DATA
126                               !POINTS) EACH RECORD CAN CONTAIN 106 REAL
```

TABLE B13 (CONTINUED)

```
127                                 !NUMBERS 8X106-848.
128   ASSIGN @Path1 TO Rawfile$     !ASSIGNS A PATH NAME TO THE RAW FILE JUST
129                                 !CREATED FOR ENTER AND OUTPUT STATEMENTS.
130   MASS STORAGE IS "/CLASSICK/REDDATA"
132   PRINT "************************************************************"
133   PRINT ""
134   PRINT "NAME FILE TO STORE THE RAW DATA SCALED TO ENGINEERING UNITS"
135   INPUT Sclfile$
136   CREATE BDAT Sclfile$,100,948
137   ASSIGN @Path2 TO Sclfile$
138   PRINT "************************************************************"
139   PRINT ""
140   PRINT "ENTER THE ATMOSPHERIC PRESURE IN INCHES HG"
141   INPUT Pbaro
142   PRINT ""
143   PRINT "************************************************************"
144   PRINT ""
145   PRINT "PRESS ""ONE PROBE"" IF ONE PROBE IS USED."
146   PRINT "PRESS ""TWO PROBES"" IF TWO PROBES ARE USED."
147   PRINT ""
148   PRINT "************************************************************"
149   PRINT ""
150   ON KEY 1 LABEL "ONE     PROBE" GOTO Numberprbs1  !CODING FOR SOFT KEYS
151   ON KEY 4 LABEL "TWO     PROBES" GOTO Numberprbs2
152 Spin1:      GOTO Spin1                    !KEEPS SOFT KEY LABELS ON SCREEN UNTIL
153                                           !EITHER SOFT KEY IS PRESSED.
154 Numberprbs1:    Noofprbs=1                !NUMBER OF PROBES DETERMINES WHERE TO
155                                           !GO IN THE PROGRAM.
157   GOTO Checknoofprbs
158 Numberprbs2:  Noofprbs=2
159 Checknoofprbs:  IF Noofprbs=2 THEN
160 Start2prbs:  INPUT "ENTER THE SCAN NUMBER, LOWER PROBE  POSITION AND UPPER P
161   ELSE
162 Start1prb:INPUT "ENTER THE SCAN NUMBER AND PROBE POSITION",Scan,Posit
163   PRINT ""
164   PRINT "************************************************************"
165   END IF
166   COM /Positvrbls/ Svc,Scn        !COMMON BLOCK VARIABLES USED IN POSITIONING
167                                   !THE SCANIVALVE PORTS.
169   COM /Readvrbls/ Scan,Dvm,Scanvb(1,48),Tempchnrd,Yawchnrd,Scnyawchn,Scntemp
170   COM /Readvrbls/ Yawchnrd1,Scnyawchnu,Scnyawchnl,Maxdif
171                                   !ABOVE COMMON BLOCK VARIABLES USED IN
172                                   !OBTAINING DVM READINGS.
174   IF Noofprbs=2 THEN
175     GOTO Read2prbs
176   ELSE
177     GOTO Read1prb
178   END IF
179 Read2prbs:PRINT "SCAN NUMBER";Scan
180   PRINT "LOWER PROBE POSITION";Positl
181   PRINT "UPPER PROBE POSITION";Positu
182   PRINT "PORT          VOLTAGE              GAUGE PRESS(INCHES H2o) "
183   MAT Scanvb= (0)
184   FOR Db=Dporth TO Nporth
185     CALL Scnvportposit(Scnvb,Db,Scnhmsvcb,Scnstpsvcb)    !CALLS SUBROUTINE
186                              !TO POSITION SCANIVALVE PORTS. INITIALLY IT WILL
187                              !POSITION SCNIVALVE TO PORT 1.
188     CALL Readdvm(Db,Scnrdsvcb)               !CALLS SUBROUTINE TO READ THE
190                                              !THE SCANIVALVE PORT READINGS ON
191                                              !THE DVM.
193     Prntdatb(1,1)=Scanvb(1,1)*10000          !CONVERTS DVM READINGS TO PRESSURE
194                                              !VALUES.
196   IF Db>1 THEN Prntdatb(1,Db)=Scanvb(1,Db)*10000-Prntdatb(1,1)  !ALLOWS
```

TABLE B13 (CONTINUED)

```
197                                                        !PORT 1 READING TO BE SUBTRACTED
198                                                        !FROM OTHER READINGS.
200   PRINT USING "DD,10X,MD.3DE,10X,MD.3DE";Db,Scanvb(1,Db),Prntdatb(1,Db)
201   NEXT Db
202   CALL Readdvm(Db,Scnyauchnl)            !Db IN THIS CONTEXT ACTS AS A DUMMY
203                            !VARIABLE. DVM READS THE LOWER PROBE YAW TRANSDUCER.
204   CALL Readdvm(Db,Scnyauchnu)            !UPPER PROBE YAW TRANSDUCER IS READ.
205   PRINT "*******************************************************"
206   PRINT "LOWER PROBE YAW CHAN READING      ";Yauchnrdl
207   Yaul=Yauchnrdl*1000                     !THIS IS WHERE THE REFERENCING
208                                           !CORRECTION FOR THE YAW ANGLE IS MADE
210   PRINT "LOWER PROBE YAW (DEGREES)         ";Yaul
211   PRINT "UPPER PROBE YAW CHAN READING      ";Yauchnrdu
212   Yauu=Yauchnrdu*1000                     !MAKE THE REFERENCING CORRECTION FOR
213                                           !UPPER PROBE YAW ANGLE HERE.
215   PRINT "UPPER PROBE YAW (DEGREES)         ";Yauu
216   GOTO Continue
217 Read1prb:PRINT "SCAN NUMBER";Scan        !CODING FOR READING ONE PROBE BEGINS
218   PRINT "PROBE POSITION";Posit
219   PRINT "PORT           VOLTAGE      GUAGE PRESSURE(INCHES H2o)"
220   MAT Scanvb= (0)
221   FOR D=Dport TO Hport
222     CALL Scnvportposit(Scnvb,D,Scnhmsvcb,Scnstpsvcb)    !CALLS SUBROUTINE TO
223                                       !POSITION SCANIVALVE PORT.
225     CALL Readdvm(D,Scnrdsvc)        !CALLS SUBROUTINE TO READ SCANIVALVE PORTS
226                                       !ON THE DVM.
228    Prntdatb(1,1)=Scanvb(1,1)*10000              !SCALES DVM READINGS TO
229                                                 !TO ENGINEERING UNITS.
231   IF D>1 THEN Prntdatb(1,D)=Scanvb(1,D)*10000-Prntdatb(1,1)     !PORT 1
232                                       !READING SUBTRACTED OFF THE SCANIVALVE
233                                       !PORT READINGS.
235     PRINT USING "DD,10X,MD.3DE,10X,MD.3DE";D,Scanvb(1,D),Prntdatb(1,D)
236   NEXT D
237   PRINT "**********************************************************"
238   CALL Readdvm(D,Scnyauchn)
239   PRINT "YAW CHAN READING                 ";Yauchnrd
240   Yau=Yauchnrd*1000       !THIS IS WHERE TO CORRECT FOR PROBE YAW REFERENCING
241   PRINT "YAW (DEGREES)                    ";Yau
242 Continue:CALL Readdvm(Db,Scntempchn)
243   PRINT "TEMP CHAN READING                ";Tempchnrd
244   T=Tempchnrd*1000
245   Temp=33.91*T+34.25+460              !IRON CONSTANTAN THERMOCOUPLE EQUATION
246                                       !SAME ONE USED BY DREON.
248   PRINT "TEMPERATURE (DEGREES R)          ";Temp
249   Pa=Pbaro*13.57                  !ATMOSPHERIC PRESS CONVERTED TO INCHES H2o
250   PRINT USING "26A,4X,2D.2D,X,4A,5X,3D.2D,5A";"ATMOSPHERIC PRESS (INCHES)",P
251   PRINT ""
252   PRINT "************************************************************"
253   PRINT ""
254   PRINT "IS DATA OK? PRESS ""RECORD"" TO RECORD DATA, PRESS ""REPEAT"" TO"
255   PRINT "REPEAT THE SCAN."
256   PRINT ""
257   PRINT "************************************************************"
258   ON KEY 1 LABEL "RECORD" GOTO Storerawdata
259   ON KEY 4 LABEL "REPEAT" GOTO Repeatscan
260 Spin2:    GOTO Spin2
261 Repeatscan:    IF Noofprbs=2 THEN
262       GOTO Start2prbs
263     ELSE
264       GOTO Start1prb
265     END IF
266 Storerawdata:    ! STORE RAWDATA TO RAWDATA FILE
267   IF Noofprbs=2 THEN
```

TABLE B13 (CONTINUED)

```
268   MAT Rawdat= (0)
269   FOR K=1 TO 19
270   Rawdat(1,K)=Scanvb(1,K)         !ASSIGN ALL THE SCANIVALVE READINGS IN THE
271                                   !SCANVB ARRAY TO THE RAWDAT ARRAY ELEMENT
272                                   !BY ELEMENT
274   NEXT K
275   Rawdat(1,20)=Positl
276   Rawdat(1,21)=Positu
277   Rawdat(1,22)=Yawchnrdl
278   Rawdat(1,23)=Yawchnrdu
279   Rawdat(1,24)=Tempchnrd
280   Rawdat(1,25)=Pa
281   OUTPUT @Path1,Scan;Rawdat(*)            !THE DATA IS STORED IN THE RAW DATA
282                                           !FILE WHICH WAS PREVIOUSLY CREATED.
283                                           !THIS IS A RANDOM OUTPUT STATEMENT.
285   MAT Scaled= (0)
286   FOR K=1 TO 19
287   Scaled(1,K)=Prntdatb(1,K)               !SAME METHOD HERE EXCEPT SCALED DATA
288                                           !IS REASSIGNED.
290   NEXT K
291   Scaled(1,20)=Positl
292   Scaled(1,21)=Positu
293   Scaled(1,22)=Yawl
294   Scaled(1,23)=Yawu
295   Scaled(1,24)=Temp
296   Scaled(1,25)=Pa
297   OUTPUT @Path2,Scan;Scaled(*)
298   ELSE
299   MAT Rawdat= (0)
300   FOR K=1 TO 14                          !FOR THE ONE PROBE OPTION, ASSIGNS
301                                          !ALL THE SCANIVALVE READINGS IN THE
302                                          !ARRAY TO THE RAWDAT ARRAY ELEMENT
303                                          !BY ELEMENT.
305   Rawdat(1,K)=Scanvb(1,K)
306   NEXT K
307   Rawdat(1,15)=Posit
308   Rawdat(1,16)=Yawchnrd
309   Rawdat(1,17)=Tempchnrd
310   Rawdat(1,18)=Pa
311   OUTPUT @Path1,Scan;Rawdat(*)           !THE DATA IS STORED IN THE RAW DATA
312                                          !WHICH WAS PREVIOUSLY CREATED. THIS
313                                          !IS A RANDOM OUTPUT STATEMENT.
315   MAT Scaled= (0)
316   FOR K=1 TO 14
317   Scaled(1,K)=Prntdatb(1,K)              !SAME METHOD HERE EXCEPT SCALED DATA
318                                          !IS REASSIGNED.
320   NEXT K
321   Scaled(1,15)=Posit
322   Scaled(1,16)=Yaw
323   Scaled(1,17)=Temp
324   Scaled(1,18)=Pa
325   OUTPUT @Path2,Scan;Scaled(*)
326   END IF
327   PRINT "************************************************************"
328   PRINT ""
329   PRINT "PRESS ""GO ON"" TO CONTINUE TAKING DATA, PRESS ""END PRB DATA"""
330   PRINT "TO TERMINATE PROBE DATA COLLECTION."
331   PRINT ""
332   PRINT "**************************************************************"
333   ON KEY 1 LABEL "END PRB DATA" GOTO Printfilename
334   ON KEY 4 LABEL "GO ON" GOTO Collectdata
335 Spin3:   GOTO Spin3
336 Collectdata:  IF Noofprbs=2 THEN
```

```
337          GOTO Start2prbs
338        ELSE
339        GOTO Start1prb
340      END IF
341      PRINT "***********************************************************"
342      PRINT ""
343 Printfilename:  PRINT "RAW PROBE DATA IS STORED "
344                 PRINT "IN DATA FILE",Rawfile$
345                 PRINT ""
346  PRINT "***********************************************************"
347  PRINT ""
348  PRINT "PROBE RAW DATA SCALED TO ENGINEERING UNITS"
349  PRINT "IS STORED IN REDDATA FILE",Sclfile$
350  PRINT ""
351  PRINT "***********************************************************"
352  PRINT ""
353  PRINT "ENSURE THE PROBE IS CLEAR OF THE INSTRUMENTED BLADE."
354  PRINT ""
355  PRINT "***********************************************************"
356  PRINT ""
357  PRINT " PRESS ""COLLECT DATA"" TO COLLECT DATA FOR THE INSTRUMENTED BLADE"
358  PRINT " PRESS ""GO ON"" TO CONTINUE WITH THE PROGRAM."
359  PRINT ""
360  ON KEY 4 LABEL "GO ON" GOTO Printoption1
361  ON KEY 1 LABEL "COLLECT DATA" GOTO Namefile
362 Spin4:  GOTO Spin4
363 Namefile:  MASS STORAGE IS "/CLASSICK/DATA"      !CODING FOR INSTRUMENTED
364                                           !BLADE SECTION OF PROGRAM IS SAME AS FOR
366  PRINT "***********************************************************"
367  PRINT ""
368  PRINT "NAME FILE FOR THE RAW DATA TO BE COLLECTED FROM THE BLADE."
369  INPUT Rawbladfile$
370  CREATE BDAT Rawbladfile$,100,384  !100 RECORDS, EACH RECORD CAN CONTAIN
371                                    !48 REAL NUMBERS 8X48=384.
373  ASSIGN @Path3 TO Rawbladfile$
374  MASS STORAGE IS "/CLASSICK/REDDATA"
375  PRINT "***********************************************************"
376  PRINT ""
377  PRINT "NAME FILE FOR THE RAW BLADE DATA SCALED TO ENGINEERING UNITS."
378  INPUT Sclbladfile$
379  PRINT ""
380  PRINT "***********************************************************"
381  CREATE BDAT Sclbladfile$,100,384
382  ASSIGN @Path4 TO Sclbladfile$
383 Bladeread:   MAT Scanva= (0)
384   PRINT "SCAN NUMBER",Scan
385   PRINT "PORT           VOLTAGE              GUAGE PRESS(INCHES H2o)"
386   FOR Da=Dporta TO Hporta
387   CALL Scnvportposit(Scnva,Da,Scnhmsvca,Scnstpsvca)
388   CALL Readdvm(Da,Scnrdsvca)
389   Prntdata(1,Da)=Scanva(1,Da)*10000
390  IF Da>1 THEN Prntdata(1,Da)=Scanva(1,Da)*10000-Prntdata(1,1)
391   PRINT USING "DD,10X,MD.3DE,10X,MD.3DE";Da,Scanva(1,Da),Prntdata(1,Da)
392   NEXT Da
393   PRINT "***********************************************************"
394   PRINT ""
395   PRINT "IS DATA OK? PRESS ""REPEAT"" TO REPEAT THE SCAN, PRESS ""RECORD"""
396   PRINT "TO RECORD THE DATA."
397   PRINT ""
398   PRINT "***********************************************************"
399   ON KEY 1 LABEL "RECORD" GOTO Storedata
400   ON KEY 4 LABEL "REPEAT" GOTO Bladeread
401 Spin5:   GOTO Spin5
```

```
402 Storedata:  OUTPUT @Path3;Scanva(*)
403   OUTPUT @Path4;Prntdata(*)
404   PRINT "THIS DATA IS ASSOCIATED WITH THE LAST SCAN OF FILE  ",Sclfile$
405   PRINT ""
406 Printoption1:  PRINT "**************************************************
407  PRINT ""
408  PRINT "ALIGN PAPER IN PRINTER. "
409  PRINT ""
410  PRINT "TO PRINT OUT A TABULATION OF THE RAW DATA COLLECTED FROM"
411  PRINT ""
412  PRINT "THE PROBE(S), PRESS ""RAW TABLE"". PRESS ""GO ON"""
413  PRINT ""
414  PRINT "TO CONTINUE WITH THE PROGRAM."
415  PRINT ""
416  PRINT "************************************************************"
417  ON KEY 1 LABEL "RAW     TABLE" GOTO Printrawtable
418  ON KEY 4 LABEL "GO ON" GOTO Printoption2
419 Spin5:  GOTO Spin6
420 Printrawtable:  MASS STORAGE IS "/CLASSICK/DATA"
421  ASSIGN @Path1 TO Rawfile$     !STATEMENT PUTS FILE POINTER AT BEGINING
422                                !OF FILE.
424  PRINT ""
425  PRINT "PRESS ""ONE PROBE"" IF ONE PROBE WAS USED."
426  PRINT "PRESS ""TWO PROBES"" IF TWO PROBES WERE USED."
427  PRINT ""
428  PRINT "**************************************************************"
429  ON KEY 1 LABEL "ONE     PROBE" GOTO Numberofprbs1
430  ON KEY 4 LABEL "TWO     PROBES" GOTO Numberofprbs2
431 Spin7:  GOTO Spin7
432 Numberofprbs1:  Noofprbs=1
433 GOTO Howmanyprbs
434 Numberofprbs2: Noofprbs=2
435 Howmanyprbs:      IF Noofprbs=2 THEN
436  PRINTER IS Prnter        !SENDS PRINT STATEMENTS TO THE PRINTER.
437  PRINT "**************************************************"
438  PRINT "PROBE RAW DATA FILE   ",Rawfile$
439  PRINT "**************************************************"
440  PRINT "SCAN   L PRO      1            2             3            4
441  PRINT "        POSIT"
442      FOR N=1 TO 100
443      ENTER @Path1,N;Rawdat(*)          !STATEMENT ACCESSES THE RAW DATA FILE IN
444                                        !RANDOM MODE.
446      ON END @Path1 GOTO Twoprintraw1       !SINCE ALL RECORDS OF A FILE MAY
447                                        !NOT BE FILLED (RECALL 100 RECORDS WERE
448                                        !RESERVED FOR 100 DATA POINTS), THE ON
449                                        !END STATEMENT ALLOWS THE PROGRAM TO
450                                        !CONTINUE AT THE Twoprintraw1 LINE WHEN
451                                        !AN END OF FILE CONDITION OCCURS.
453      Posit1=Rawdat(1,20)
454      Port1=Rawdat(1,1)
455      Port2=Rawdat(1,2)
456      Port3=Rawdat(1,3)
457      Port4=Rawdat(1,4)
458      Port5=Rawdat(1,5)
459  PRINT USING "4D,3X,4D.2D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE"
460  NEXT N
461 Twoprintraw1:  PRINT "*******************************************************
462  PRINT "SCAN   6           7             8             9            10
463  FOR N=1 TO 100
464  ENTER @Path1,N;Rawdat(*)
465  ON END @Path1 GOTO Twoprintraw2
466      Port6=Rawdat(1,6)
467      Port7=Rawdat(1,7)
```

TABLE B13 (CONTINUED)

```
468        Port8=Rawdat(1,8)
469        Port9=Rawdat(1,9)
470        Port10=Rawdat(1,10)
471        Port11=Rawdat(1,11)
472  PRINT USING "4D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,2X,MD.3DE,2X,MD.3DE
473  NEXT N
474 Twoprintraw2:  PRINT "****************************************************
475 PRINT "SCAN   U PRB      12              13              14              15
476    PRINT "          POSIT"
477    FOR N=1 TO 100
478    ENTER @Path1,N;Rawdat(*)
479    ON END @Path1 GOTO Twoprintraw3
480    Positu=Rawdat(1,21)
481    Port12=Rawdat(1,12)
482    Port13=Rawdat(1,13)
483    Port14=Rawdat(1,14)
484    Port15=Rawdat(1,15)
485    Port16=Rawdat(1,16)
486  PRINT USING "4D,3X,4D.2D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE"
487  NEXT N
488 Twoprintraw3:  PRINT "****************************************************
489  PRINT "SCAN   17             18              19 "
490  FOR N=1 TO 100
491  ENTER @Path1,N;Rawdat(*)
492  ON END @Path1 GOTO Twoprintraw4
493  Port17=Rawdat(1,17)
494  Port18=Rawdat(1,18)
495  Port19=Rawdat(1,19)
496  Pa=Rawdat(1,25)
497  PRINT USING "4D,3X,MD.3DE,4X,MD.3DE,4X,MD.3DE";N,Port17,Port18,Port19
498  NEXT N
499 Twoprintraw4:  PRINT "****************************************************
500   PRINT "SCAN    YAW L          YAW U          TEMPCHN        ATMOS"
501   PRINT "        VOLT           VOLT           VOLT           PRESSURE"
502  FOR N=1 TO 100
503  ENTER @Path1,N;Rawdat(*)
504  ON END @Path1 GOTO Twoprintraw5
505  Yawchnrdl=Rawdat(1,22)
506  Yawchnrdu=Rawdat(1,23)
507  Tempchnrd=Rawdat(1,24)
508  Pa=Rawdat(1,25)
509  PRINT USING "4D,3X,MD.3DE,4X,MD.3DE,4X,MD.3DE,4X,3D.2D";N,Yawchnrdl,Yawchnr
510   NEXT N
511 Twoprintraw5:  OFF END @Path1           !TERMINATES THE ON END COMMAND
512                ELSE
513   PRINTER IS Prnter
514   PRINT "******************************************"
515   PRINT "PROBE RAW DATA FILE   ",Rawfile$
516   PRINT "******************************************"
517   PRINT "SCAN  PROBE    1              2              3              4              5"
518   PRINT "       POSIT"
519   FOR N=1 TO 100
520   ENTER @Path1,N;Rawdat(*)         !STATEMENT ACCESSES THE RAW DATA FILE IN
521                                    !RANDOM MODE
523   ON END @Path1 GOTO Printraw1     !SINCE ALL RECORDS OF A FILE MAY NOT BE
524                                    !FILLED (RECALL 100 WERE USED FOR 100
525                                    !DATA POINTS), ON END STATEMENT ALLOWS THE
526                                    !PROGRAM TO CONTINUE AT THE Printraw1 LINE
528   Posit=Rawdat(1,15)
529   Port1=Rawdat(1,1)
530   Port2=Rawdat(1,2)
531   Port3=Rawdat(1,3)
532   Port4=Rawdat(1,4)
```

```
533    Port5=Rawdat(1,5)
534    PRINT USING "4D,2X,4D.2D,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE
535    NEXT N
536 Printraw1:   PRINT "**********************************************************
537  PRINT "SCAN  6            7            8            9            10          11
538  FOR N=1 TO 100
539  ENTER @Path1,N;Rawdat(*)
540  ON END @Path1 GOTO Printraw2
541  Port6=Rawdat(1,6)
542  Port7=Rawdat(1,7)
543  Port8=Rawdat(1,8)
544  Port9=Rawdat(1,9)
545  Port10=Rawdat(1,10)
546  Port11=Rawdat(1,11)
547  PRINT USING "4D,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE
548  NEXT N
549 Printraw2:   PRINT "*********************************************************
550  PRINT "SCAN  12           13           14           YAWCHAN      TEMPCHAN     AT
551  PRINT "                                            VOLTAGE      VOLTAGE      PR
552  FOR N=1 TO 100
553  ENTER @Path1,N;Rawdat(*)
554  ON END @Path1 GOTO Printraw3
555  Port12=Rawdat(1,12)
556  Port13=Rawdat(1,13)
557  Port14=Rawdat(1,14)
558  Yawchnrd=Rawdat(1,16)
559  Tempchnrd=Rawdat(1,17)
560  Pa=Rawdat(1,18)
561  PRINT USING "4D,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,3D.2D"
562  NEXT N
563 Printraw3:   PRINT "*********************************************************
564   OFF END @Path1          !TERMINATES ON END STATEMENT
565   END IF
566   PRINTER IS Scren        !RETURNS PRINT STATEMENTS TO MONITOR.
567   PRINT "*************************************************************"
568   PRINT ""
569 Printoption2: PRINT "ALIGN PAPER IN PRINTER."
570               PRINT ""
571               PRINT "TO PRINTOUT A TABULATION OF THE PROBE DATA SCALED IN"
572               PRINT ""
573               PRINT "ENGINEERING UNITS, PRESS ""SCALED DATA""."
574               PRINT ""
575               PRINT "PRESS ""GO ON""TO CONTINUE WITH THE PROGRAM."
576  PRINT ""
577  PRINT "*************************************************************"
578  ON KEY 1 LABEL " SCALED  DATA" GOTO Prntscaledtable
579  ON KEY 4 LABEL "GO ON" GOTO Printoption3
580 Spin8:  GOTO Spin8
581 Prntscaledtable:      MASS STORAGE IS "/CLASSICK/REDDATA"
582        ASSIGN @Path2 TO Sclfile$
583        PRINT ""
584 PRINT "PRESS ""ONE PROBE"" IF ONE PROBE WAS USED."
585 PRINT "PRESS ""TWO PROBES "" IF TWO PROBES WERE USED."
586 PRINT ""
587 PRINT "*************************************************************"
588 ON KEY 1 LABEL "ONE     PROBE" GOTO Numberprobes1
589 ON KEY 4 LABEL "TWO     PROBES" GOTO Numberprobes2
590 Spin9: GOTO Spin9
591 Numberprobes1:  Noofprbs=1
592 GOTO Howmanyprobes
593 Numberprobes2: Noofprbs=2
594 Howmanyprobes:      IF Noofprbs=2 THEN
595  PRINTER IS Prnter
```

```
596  PRINT "**************************************************"
597  PRINT "PROBE SCALED DATA FILE   ",Sclfile$
598  PRINT "**************************************************"
599  PRINT "SCAN   L PRB      1              2              3              4
600  PRINT "        POSIT"
601      FOR N=1 TO 100
602      ENTER @Path2,N;Scaled(*)
603      ON END @Path2 GOTO Tuoprintscl1
604      Positl=Scaled(1,20)
605      Port1=Scaled(1,1)
606      Port2=Scaled(1,2)
607      Port3=Scaled(1,3)
608      Port4=Scaled(1,4)
609      Port5=Scaled(1,5)
610  PRINT USING "4D,3X,4D.2D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE"
611  NEXT N
612 Tuoprintscl1:  PRINT "****************************************************
613  PRINT "SCAN   6              7              8              9              10
614  FOR N=1 TO 100
615  ENTER @Path2,N;Scaled(*)
616  ON END @Path2 GOTO Tuoprintscl2
617       Port6=Scaled(1,6)
618       Port7=Scaled(1,7)
619       Port8=Scaled(1,8)
620       Port9=Scaled(1,9)
621       Port10=Scaled(1,10)
622       Port11=Scaled(1,11)
623  PRINT USING "4D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,2X,MD.3DE,2X,MD.3DF
624  NEXT N
625 Tuoprintscl2:  PRINT "****************************************************
626  PRINT "SCAN   U PRB      12             13             14             15
627  PRINT "        POSIT"
628    FOR N=1 TO 100
629    ENTER @Path2,N;Scaled(*)
630    ON END @Path2 GOTO Tuoprintscl3
631    Positu=Scaled(1,21)
632    Port12=Scaled(1,12)
633    Port13=Scaled(1,13)
634    Port14=Scaled(1,14)
635    Port15=Scaled(1,15)
636    Port16=Scaled(1,16)
637  PRINT USING "4D,3X,4D.2D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DF,3X,MD.3DF"
638  NEXT N
639 Tuoprintscl3:  PRINT "****************************************************
640   PRINT "SCAN   17             18             19 "
641  FOR N=1 TO 100
642  ENTER @Path2,N;Scaled(*)
643  ON END @Path2 GOTO Tuoprintscl4
644  Port17=Scaled(1,17)
645  Port18=Scaled(1,18)
646  Port19=Scaled(1,19)
647  PRINT USING "4D,3X,MD.3DE,4X,MD.3DE,4X,MD.3DE";N,Port17,Port18,Port19
648  NEXT N
649 Tuoprintscl4:  PRINT "****************************************************
650   PRINT "SCAN   YAW L          YAW U          TEMP           ATMOS"
651   PRINT "       DEG            DEG            (R)            PRESSURE"
652  FOR N=1 TO 100
653  ENTER @Path2,N;Scaled(*)
654  ON END @Path2 GOTO Tuoprintscl5
655  Yawl=Scaled(1,22)
656  Yawu=Scaled(1,23)
657  Temp=Scaled(1,24)
658  Pa=Scaled(1,25)
```

```
659  PRINT USING "4D,3X,MD.3DE,4X,MD.3DE,4X,MD.3DE,4X,3D.2D";N,Yaw1,Yaw,Temp,Pa
660  NEXT N
661 Twoprint=-15:  OFF END @Path2
662                ELSE
663              ! END IF
664   PRINTER IS Prnter
665   PRINT "**************************************************"
666   PRINT "PROBE SCALED DATA FILE   ",Sclfile$
667   PRINT "**************************************************"
668   PRINT "SCAN   PROBE      1               2              3              4
669   PRINT "       POSIT"
670   FOR N=1 TO 100
671   ENTER @Path2,N;Scaled(*)
672   ON END @Path2 GOTO Printscl1
673   Posit=Scaled(1,15)
674   Port1=Scaled(1,1)
675   Port2=Scaled(1,2)
676   Port3=Scaled(1,3)
677   Port4=Scaled(1,4)
678   Port5=Scaled(1,5)
679   PRINT USING "4D,3X,4D.2D,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE,3X,MD.3DE
680   NEXT N
681 Printscl1:   PRINT "**********************************************************
682  PRINT "SCAN  6            7            8            9            10           11
683  FOR N=1 TO 100
684  ENTER @Path2,N;Scaled(*)
685  ON END @Path2 GOTO Printscl2
686  Port6=Scaled(1,6)
687  Port7=Scaled(1,7)
688  Port8=Scaled(1,8)
689  Port9=Scaled(1,9)
690  Port10=Scaled(1,10)
691  Port11=Scaled(1,11)
692  PRINT USING "4D,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE
693  NEXT N
694 Printscl2:   PRINT "**********************************************************
695  PRINT "SCAN  12           13           14           YAW          TEMP         AT
696  PRINT "                                             DEG          (R)          PR
697  FOR N=1 TO 100
698  ENTER @Path2,N;Scaled(*)
699  ON END @Path2 GOTO Printscl3
700  Port12=Scaled(1,12)
701  Port13=Scaled(1,13)
702  Port14=Scaled(1,14)
703  Yaw=Scaled(1,16)
704  Temp=Scaled(1,17)
705  Pa=Scaled(1,18)
706  PRINT USING "4D,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,MD.3DE,2X,3D.2D"
707  NEXT N
708 Printscl3:  PRINT "***********************************************************
709   OFF END @Path2
710   END IF
711  PRINTER IS Screen
712  PRINT "*************************************************************"
713   PRINT ""
714 Printoption3: PRINT "PRESS ""BLADE DATA"" FOR BLADE DATA PRINT OPTIONS."
715               PRINT ""
716               PRINT "PRESS ""GO ON"" TO CONTINUE PROGRAM."
717               PRINT ""
718  PRINT "**************************************************************
719  ON KEY 1 LABEL "BLADE   DATA" GOTO Printoption4
720  ON KEY 4 LABEL "GO ON" GOTO Loadoption1
721 Spin10:  GOTO Spin10
```

```
722 Printoption4: PRINT ""
723               PRINT "ALIGN PAPER IN PRINTER."
724               PRINT ""
725               PRINT "TO PRINT OUT A TABULATION OF THE RAW BLADE DATA"
726               PRINT ""
727               PRINT "PRESS ""BLADE DATA"". PRESS ""GO ON"" TO CONTINUE."
728               PRINT ""
729      PRINT "****************************************************************
730      ON KEY 1 LABEL "BLADE   DATA" GOTO Prntbladedata
731      ON KEY 4 LABEL "GO ON" GOTO Printoption5
732 Spin11:      GOTO Spin11
733 Prntbladedata:      MASS STORAGE IS "/CLASSICK/DATA"
734      ASSIGN @Path3 TO Rawbladfile$
735      PRINTER IS Prnter
736      PRINT "******************************************************"
737      PRINT "BLADE RAW DATA FILE    ",Rawbladfile$
738      PRINT "******************************************************"
739      PRINT ""
740      PRINT "PROBE DATA ASSOCIATED WITH THE BLADE DATA IS CONTAINED"
741      PRINT "IN FILE:  ",Rawfile$
742      PRINT "SCAN:",Scan
743      PRINT "SCANIVALVE                VOLTAGE"
744      PRINT "PORT                      READING"
745      FOR N=1 TO 48
746      ENTER @Path3;Scanva(1,N)
747      PRINT USING "DD,20X,MD.3DE";N,Scanva(1,N)
748      NEXT N
749      PRINTER IS Scren
750 Printoption5:  PRINT "******************************************************"
751      PRINT ""
752      PRINT "ALIGN PAPER IN PRINTER."
753      PRINT ""
754      PRINT "TO PRINT OUT A TABULATIION OF THE BLADE DATA SCALED TO "
755      PRINT ""
756      PRINT "ENGINEERING UNITS, PRESS ""SCALED DATA""."
757      PRINT ""
758      PRINT "PRESS ""GO ON"" TO TERMINATE PROGRAM."
759      PRINT ""
760      ON KEY 1 LABEL "SCALED  DATA" GOTO Prntscldbladdat
761      ON KEY 4 LABEL "GO ON" GOTO Loadoption1
762 Spin12:      GOTO Spin12
763 Prntscldbladdat:      MASS STORAGE IS "/CLASSICK/REDDATA"
764      ASSIGN @Path4 TO Sclbladfile$
765      PRINTER IS Prnter
766      PRINT "******************************************************"
767      PRINT "BLADE SCALED DATA FILE    ",Sclbladfile$
768      PRINT "******************************************************"
769      PRINT ""
770      PRINT "PROBE DATA ASSOCIATED WITH THE BLADE DATA IS CONTAINED"
771      PRINT "IN FILE:  ",Sclfile$
772      PRINT "SCAN:",Scan
773      PRINT "SCANIVALVE               PRESS (INCHES H2o)"
774      PRINT "PORT"
775      FOR N=1 TO 48
776      ENTER @Path4;Prntdata(1,N)
777      PRINT USING "DD,20X,MD.3DE";N,Prntdata(1,N)
778      NEXT N
779 Loadoption1:  PRINTER IS Scren
780      PRINT "******************************************************"
781      PRINT ""
782      PRINT "TO LOAD PROGRAM TO REDUCE THE ACQUIRED DATA"
783      PRINT ""
784      PRINT "PRESS ""CALC"".  PRESS ""GO ON"" TO TERMINATE THE PROGRAM"
```

TABLE B13 (CONTINUED)

```
785       PRINT ""
786       PRINT "************************************************************"
787       ON KEY 1 LABEL "CALC" GOTO Loadup1
788       ON KEY 4 LABEL "GO ON" GOTO Fin
789 Spin13:      GOTO Spin13
790 Loadup1: MASS STORAGE IS "/CLASSICK/PROGS"
791           LOAD "CALC",10
792 Fin: PRINT "************************************************************"
793       PRINT "************************************************************"
794       PRINT ""
795       PRINT "                         END OF PROGRAM"
796       PRINT ""
797       PRINT "************************************************************"
798       PRINT "************************************************************"
799       END
```

TABLE B14

SUBACQUIRE PROGRAM LISTING

```
10     !FILE SUBACQUIRE
       !THIS FILE CONTAINS THE SUBPROGRAMS FOR POSITIONING THE SCANIVALVE
20     !PORTS AND READING THE DVM.
720    SUB Scnvportposit(Scnv,Dp,Scnhmsvc,Scnstpsvc)    !THE STRUCTURE OF THIS
721                                            !SUBPROGRAM IS SIMILAR TO PREVIOUS
722                                            !ACQUISITION PROGRAMS WRITTEN AT THE
723                                            !IPL. SEE GEOPFARTH THESIS.
725      OPTION BASE 1
726      COM /Positvrbls/ Svc,Scn
727 Posit:OUTPUT Svc USING "#,K";Scnv
728      Z=SPOLL(Svc)
729      U=BINAND(Z,15)
730      V=SHIFT(Z,4)
731      T=BINAND(V,7)
732      P=10*T+U                               !P IS THE PRESENT PORT THAT THE
733                                             !SCANIVALVE IS ON.
735      CLEAR Svc
736      IF P=Dp THEN Retrn
737      IF P>Dp THEN
738        OUTPUT Scn USING "ZZ";Scnhmsvc   !HOME THE SCANIVALVE
739        CLEAR Scn
740        WAIT 4                              !ALLOW 4 SECONDS FOR THE HOME TO
741                                            !COMPLETE.
743        GOTO Posit
744      ELSE
745        OUTPUT Scn USING "ZZ";Scnstpsvc !STEP THE SCANIVALVE
746        CLEAR Scn
747        WAIT .1                             !WAIT 1/10 SEC BETWEEN STEPS
748        GOTO Posit
749      END IF
750 Retrn: SUBEND
751    SUB Readdvm(Dp,Chanlasipn)
752      OPTION BASE 1
753      COM /Positvrbls/ Svc,Scn
754      COM /Readvrbls/ Scan,Dvm,Scanvb(1,48),Tempchnrd,Yauchnrd,Scnyauchn,Scnte
755      COM /Readvrbls/ Yauchnrdl,Scnyauchnu,Scnyauchnl,Maxdif
756      OUTPUT Scn USING "ZZ";Chanlasipn    !CHANLASIGN TAKES ON THE VALUE
757                                            !ASSIGNED TO IT BY THE CALLING
758                                            !STATEMENT IN THE MAIN PROGRAM.
760      OUTPUT Dvm;F1r7m3z0h0t3               !STANDARD SETTING FOR THE DVM.
761                                            !SETS THE FUNCTIONS ON THE PANEL.
763 Sample:  DIM A(5)
764      MAT A= (0)
765      FOR I=1 TO 5                          !TAKE 5 READINGS AND STORE IN THE
766                                            !"A" ARRAY
768     TRIGGER Dvm
769        ENTER Dvm;A(I)
770        Avg=SUM(A)/I                        !AVERAGE THE 5 READINGS
771        Dev=A(I)-Avg
772        IF Dev>Maxdif THEN                  !ERROR TRAP FOR SPURIOUS DVM READINGS
773        PRINT "SAMPLE EXCEEDED MAXIMUM DEVIATION ALLOWED-SAMPLE RETAKEN"
774        GOTO Sample
775        END IF
776        WAIT .3
777      NEXT I
778      IF Noofprbs=1 THEN Readone
779        IF Chanlasign=Scnrdsvcb THEN
780          Scanvb(1,Dp)=SUM(A)/5
781        ELSE
782          IF Chanlasipn=Scnyauchnl THEN
783            Yauchnrdl=SUM(A)/5
784          ELSE
785            IF Chanlasipn=Scnyauchnu THEN
```

TABLE B14 (CONTINUED)

```
786              Yauchnrdn=SUM(A)/5
787            ELSE
788              GOTO Tempread
789            END IF
790          END IF
791        END IF
792 Readone:IF Chanlastgn=Scnrdsvc THEN
793        Scanvl(1,Dp)=SUM(A)/5
794      ELSE
795          IF Chanlastgn=Scnyauchn THEN
796          Yauchnrd=SUM(A)/5
797        ELSE
798 Tempread: Tempchnrd=SUM(A)/5
799        END IF
800      END IF
801      IF Chanlastgn=Scnrdsvca THEN Scanva(1,Dp)=SUM(A)/5
802 Retrn: CLEAR Scn
803     SUBEND
```

TABLE B15

LOSSCALC PROGRAM LISTING

```
10    !THIS SUBPROGRAM IS AN ADAPTATION OF SHREEVE'S INTEGRATION ROUTINE
20    !GIVEN IN APPENDIX B OF NPS-57SF73071A
272   SUB Datint(Lowpoint,Hipoint,D(*) Posit(*),Datint)
277   OPTION BASE 1
287   DIM A(100)
297   DIM B(100)
307   DIM C(100)
317   DIM Dint(100)
321   MAT A= (0)
322   MAT B= (0)
323   MAT C= (0)
324   MAT Dint= (0)
325   N=Hipoint-1
326   Nm1=N-1
327   FOR I=Lowpoint+1 TO N
337   A(I)=(1/(Posit(I+1)-Posit(I-1)))*(((D(I+1)-D(I))/(Posit(I+1)-Posit(I)))-((
347   B(I)=((D(I)-D(I-1))/(Posit(I)-Posit(I-1)))-((Posit(I)+Posit(I-1))*A(I))
357   C(I)=D(I)-(A(I)*Posit(I)^2)-(B(I)*Posit(I))
360   NEXT I
361   Datint=0
362   FOR I=Lowpoint+1 TO Nm1
363   Dint(I)=(A(I)+A(I+1))*(Posit(I+1)^3-Posit(I)^3)/6+(B(I)+B(I+1))*(Posit(I+1
364   Datint=Datint+Dint(I)
367   NEXT I
377   Dint(1)=A(2)*(Posit(2)^3-Posit(1)^3)/3+B(2)*(Posit(2)^2-Posit(1)^2)/2+C(2)
387   Dint(N)=A(N)*(Posit(N+1)^3-Posit(N)^3)/3+B(N)*(Posit(N+1)^2-Posit(N)^2)/2+
397   Dntint=Datint+Dint(1)+Dint(N)
407   SUBEND
```

```
10    !THIS SUBPROGRAM IS AN ADAPTATION OF SHREEVE'S INTEGRATION ROUTINE
20    !GIVEN IN APPENDIX B OF NPS-57SF73071A TO BE USED FOR MIX LOSS
272   SUB Datint1(Lowpoint,Hipoint,D(*),Posit(*),Datint1)
277   OPTION BASE 1
287   DIM A(100)
297   DIM B(100)
307   DIM C(100)
317   DIM Dint(100)
321   MAT A= (0)
322   MAT B= (0)
323   MAT C= (0)
324   MAT Dint= (0)
325   N=Hipoint-1
326   Nm1=N-1
327   FOR I=Lowpoint+1 TO N
337   A(I)=(1/((Posit(I+1)-Posit(I-1))/3))*(((D(I+1)-D(I))/((Posit(I+1)-Posit(I)
347   B(I)=((D(I)-D(I-1))/((Posit(I)-Posit(I-1))/3))-((Posit(I)/3+Posit(I-1)/3)*
357   C(I)=D(I)-(A(I)*(Posit(I)/3)^2)-(B(I)*(Posit(I)/3))
360   NEXT I
361   Datint1=0
362   FOR I=Lowpoint+1 TO Nm1
363   Dint(I)=(A(I)+A(I+1))*((Posit(I+1)/3)^3-(Posit(I)/3)^3)/6+(B(I)+B(I+1))*((
364   Datint1=Datint1+Dint(I)
367   NEXT I
377   Dint(1)=A(2)*((Posit(2)/3)^3-(Posit(1)/3)^3)/3+B(2)*((Posit(2)/3)^2-(Posit
387   Dint(N)=A(N)*((Posit(N+1)/3)^3-(Posit(N)/3)^3)/3+B(N)*((Posit(N+1)/3)^2-(P
397   Datint1=Datint1+Dint(1)+Dint(N)
407   SUBEND
```

TABLE B16

CPBLADEPLOT PROGRAM LISTING

```
1      !PROGRAM CPBLADEPLOT
2      !PROGRAM PLOTS MASS AVERAGED BLADE COEFFICIENT OF PRESSURE AGAINST
3      !THE FRACTION OF CORD X/C FROM THE LEADING EDGE.
5      MASS STORAGE IS "/CLASSICP/REDDATA"
7      INPUT "ENTER THE NAME OF THE FILE CONTAINING THE BLADE CP'S",Cpfile$
10     ASSIGN @Path1 TO Cpfile$
11     OPTION BASE 1
12     DIM Cpmassavg(40)
15     DIM Xoc(20)
16     MAT Cpmassavg= (0)
19     DATA 98.3,94.6,90.8,86.6,8 .8,78.8,71.5,64.1,56.7,49.3,41.9,34.3,26.9,19.6
20     READ Xoc(*)
26     ENTER @Path1;Cpmassavg(*)
34     GINIT
60     PLOTTER IS CRT,"INTERNAL"
61     CLEAR SCREEN
62     KEY LABELS OFF
70     GRAPHICS ON
73     X_gdu_max=100*MAX(1,RATIO)
74     Y_gdu_max=100*MAX(1,1/RATIO)
75     LORG 6
76     FOR I=-.3 TO .3 STEP .1
77     MOVE X_gdu_max/2+I,Y_gdu_max
78     LABEL "Cp VS PERCENT CHORD
79     NEXT I
83     DEG
84     LDIR 90
85     MOVE 0,Y_gdu_max/2
86     LABEL "Cp
87     LDIR 0
88     MOVE X_gdu_max/2,.1*Y_gdu_max
89     CSIZE 3,1
91     LABEL "X/C PERCENT CHORD"
92     VIEWPORT .1*X_gdu_max,.99*X_gdu_max,.15*Y_gdu_max,.9*Y_gdu_max
94     FRAME
95     WINDOW 0,100,1.0,-1.6
96     AXES 5,.2,0,1.0,2,2,2
97     CLIP OFF
98     CSIZE 2.5,.5
99     LORG 6
100    FOR I=0 TO 100 STEP 10
101    MOVE I,1.02
102    LABEL USING "#,K";I
103    NEXT I
104    LORG 8
105    FOR I=-1.6 TO 1.0 STEP .4
106    MOVE -.6,I
107    LABEL USING "DD.DD";I
108    NEXT I
109    FOR N=1 TO 20
113    PLOT Xoc(N),Cpmassavg(N+3)
114    NEXT N
115  FOR N=1 TO 20
116    PLOT Xoc(21-N),Cpmassavg(22+N)
117    NEXT N
119    END
```

TABLE B17

BETAPOSIT PROGRAM LISTING

```
1    !PROGRAM BETAPOSIT
2    !PROGRAM PLOTS BETA VS PROBE POSITION
4    MASS STORAGE IS "/CLASSICK/REDDATA"
7    INPUT "ENTER THE NAME OF THE REDUCED DATA FILE",Calcdat$
10   ASSIGN @Path1 TO Calcdat$
11   OPTION BASE 1
12   DIM Calc(100,25)
17   MAT Calc= (0)
20   Scan=49
26   ENTER @Path1;Calc(*)
50   GINIT
60   PLOTTER IS CRT,"INTERNAL"
61   CLEAR SCREEN
62   KEY LABELS OFF
70   GRAPHICS ON
73   X_gdu_max=100*MAX(1,RATIO)
74   Y_gdu_max=100*MAX(1,1/RATIO)
75   LORG 6
76   FOR I=-.3 TO .3 STEP .1
77   MOVE X_gdu_max/2+I,Y_gdu_max
78   LABEL "BETA2 VS PROBE DISPLACEMENT"
79   NEXT I
83   DEG
84   LDIR 90
85   MOVE 0,Y_gdu_max/2
86   LABEL "BETA2 (deg)"
87   LDIR 0
88   MOVE X_gdu_max/2,.1*Y_gdu_max
89   CSIZE 3,1
91   LABEL "SPAN (in)"
92   VIEWPORT .1*X_gdu_max,.99*X_gdu_max,.15*Y_gdu_max,.9*Y_gdu_max
94   FRAME
95   WINDOW -5,5,-2,8
96   AXES .1,.2,-5,-2,5,5,2
97   CLIP OFF
98   CSIZE 2.5,.5
99   LORG 6
100  FOR I=-5 TO 5 STEP 1
101  MOVE I,-2.01
102  LABEL USING "#,K";I
103  NEXT I
104  LORG 8
105  FOR I=-2 TO 8 STEP 1
106  MOVE -5.1,I
107  LABEL USING "DDD.D";I
108  NEXT I
109  FOR K=1 TO Scan
113  PLOT Calc(K,1),Calc(K,9)
114  NEXT K
117  END
```

TABLE B18

PRESSPLOT PROGRAM LISTING

```
1     !PROGRAM PREFPQREF
2     !PROGRAM PLOTS PREF-PT/QREF VS PROBE POSITION
4     MASS STORAGE IS "/CLASSICK/REDDATA"
7     INPUT "ENTER THE NAME OF THE REDUCED DATA FILE",Calcdat$
10    ASSIGN @Path1 TO Calcdat$
11    OPTION BASE 1
12    DIM Calc(100,25)
17    MAT Calc= (0)
20    Scan=78
26    ENTER @Path1;Calc(*)
50    GINIT
60    PLOTTER IS CRT,"INTERNAL"
61    CLEAR SCREEN
62    KEY LABELS OFF
70    GRAPHICS ON
73    X_gdu_max=100*MAX(1,RATIO)
74    Y_gdu_max=100*MAX(1,1/RATIO)
75    LORG 6
76    FOR I=-.3 TO .3 STEP .1
77    MOVE X_gdu_max/2+I,Y_gdu_max
78    LABEL "Pref-Pt2/Qref VS PROBE DISPLACEMENT(REF)"
79    NEXT I
83    DEG
84    LDIR 90
85    MOVE 0,Y_gdu_max/2
86    LABEL "Pref-Pt2/Qref"
87    LDIR 0
88    MOVE X_gdu_max/2,.1*Y_gdu_max
89    CSIZE 3,1
91    LABEL "BLADE-TO-BLADE(in)"
92    VIEWPORT .1*X_gdu_max,.99*X_gdu_max,.15*Y_gdu_max,.9*Y_gdu_max
94    FRAME
95    WINDOW -3,3,0,.7
96    AXES .1,.01,-3,0,5,10,2
97    CLIP OFF
98    CSIZE 2.5,.5
99    LORG 6
100   FOR I=-3 TO 3 STEP 1
101   MOVE I,-.01
102   LABEL USING "#,K";I
103   NEXT I
104   LORG 8
105   FOR I=1.0 TO 0 STEP -.1
106   MOVE -3.1,I
107   LABEL USING "DD.DD";I
108   NEXT I
109   FOR K=1 TO Scan
113   PLOT Calc(K,1),Calc(K,18)
114   NEXT K
117   END
```

TABLE B19

VVREFPLOT PROGRAM LISTING

```
1    !PROGRAM VVREFPLOT
2    !PROGRAM PLOTS V/VREF VS PROBE POSITION
4    MASS STORAGE IS "/CLASSICK/REDDATA"
5    INPUT "ENTER THE NAME OF THE REDUCED DATA FILE",Calcdat$
6    ASSIGN @Path2 TO Calcdat$
9    OPTION BASE 1
10   DIM Calc(100,25)
11   MAT Calc= (0)
12   Scan=78
14   ENTER @Path2;Calc(*)
50   GINIT
60   PLOTTER IS CRT,"INTERNAL"
61   CLEAR SCREEN
62   KEY LABELS OFF
70   GRAPHICS ON
73   X_gdu_max=100*MAX(1,RATIO)
74   Y_gdu_max=100*MAX(1,1/RATIO)
75   LORG 6
76   FOR I=-.3 TO .3 STEP .1
77   MOVE X_gdu_max/2+I,Y_gdu_max
78   LABEL "V2/Vref VS PROBE DISPLACEMENT(REF)"
79   NEXT I
83   DEG
84   LDIR 90
85   MOVE 0,Y_gdu_max/2
86   LABEL "V2/Vref"
87   LDIR 0
88   MOVE X_gdu_max/2,.1*Y_gdu_max
89   CSIZE 3,1
91   LABEL "BLADE-TO-BLADE(IN)"
92   VIEWPORT .1*X_gdu_max,.99*X_gdu_max,.15*Y_gdu_max,.9*Y_gdu_max
94   FRAME
95   WINDOW -3,3,.5,1.0
96   AXES .1,.01,-3,.50,5,10,2
97   CLIP OFF
98   CSIZE 2.5,.5
99   LORG 6
100  FOR I=-3 TO 3 STEP 1
101  MOVE I,.49
102  LABEL USING "#,K";I
103  NEXT I
104  LORG 8
105  FOR I=1.0 TO .5 STEP -.1
106  MOVE -3.1,I
107  LABEL USING "DD.DD";I
108  NEXT I
109  FOR K=1 TO Scan
113  PLOT Calc(K,1),Calc(K,7)/Calc(K,14)
114  NEXT K
117  END
```

APPENDIX C

REYNOLDS NUMBER CALCULATION

Reynolds number calculation was added to the "CALC" program. This capability was added primarily to find the Reynolds number for the (averaged) inlet flow, however it will also calculate the value for the (averaged) downstream flow. The value in general should be calculated over the same three inch interval used for loss calculations and will have the same lower- and upper-integration scan numbers as the loss inputs in most cases. However, the ability to use a different interval is provided by having the ability to enter the desired limits for the selected scans of a three inch interval.

Lines 2514 to 2530 of Table B1 contain the Reynolds number calculation process in program "CALC." Line 2577 of Table B1 produces the output in the reduced file printouts. The following is the analytical development for the Reynolds number calculation.

The Reynolds number (based on chord) is defined as

$$Re = \frac{\rho V C}{\mu} \tag{1}$$

Properties vary at the inlet so integration is required over one blade space; thus

$$Re = \int_0^s \frac{\rho V}{\mu} ds\left(\frac{c}{s}\right) = \sigma \int_0^s \frac{\rho V}{\rho ref Vref} \frac{\mu ref}{\mu} ds\left(\frac{\rho ref Vref}{\mu ref}\right) \quad \textbf{(2)}$$

which reduces to

$$Re = \frac{\rho ref Vref}{\mu ref} \int_0^s \left[\frac{k1}{\cos\beta 1}\right]\left[\frac{\mu ref}{\mu}\right] ds \quad \textbf{(3)}$$

The ensemble average of survey span Reynolds number is then defined as

$$Re_c = \sigma\left(\frac{\hat{P}_p}{R\hat{T}_p}\right) \frac{\hat{V}ref}{\hat{\mu} ref} \int_0^s \left(\frac{k_1}{\cos\beta_1}\right)\left(\frac{\mu ref}{\mu}\right) ds \quad \textbf{(4)}$$

with subscript p denoting the plenum (reference) condition.

Introducing Sutherland's Law for the viscosity

$$\frac{\mu}{\mu_0} = \frac{0.063329 T^{\frac{3}{2}}}{198.72 + T} \quad \textbf{(5)}$$

and using the calculated value X from measurements to find T

$$T = T_p(1 - X^2) \quad \textbf{(6)}$$

then,

$$U = \frac{\mu ref}{\mu} = \left[\frac{T_p}{T}\right]^{\frac{3}{2}}\left[\frac{198.72 + T}{198.72 + Tp}\right] \quad \textbf{(7)}$$

The integral in Eqn. (4) is then

$$I = \int_0^s \left(\frac{k_1}{\cos\beta_1}\right) U ds \tag{8}$$

which gives

$$Re = 12\sigma\left(\frac{\hat{P}_p}{R\hat{T}_p}\right)\frac{\hat{V}ref}{\hat{\mu}ref} I \tag{9}$$

where

$$\hat{\mu}ref = \frac{0.063329\,\hat{T}ref^{\frac{3}{2}}}{198.72+\hat{T}ref}\,\mu_0 \tag{10}$$

and

$$\hat{T}ref = \hat{T}_p(1-\hat{X}ref^2) \tag{11}$$

Eqn. (9) was used in the calculation of the Reynolds number in program "CALC" with the intermediate steps of determining $\hat{\mu}ref$, $\hat{T}ref$ and the integral I using Eqn. (10), Eqn. (11) and Eqn. (8) respectively.

APPENDIX D

CALCULATION OF COMPRESSIBLE MIXED-OUT CONDITIONS

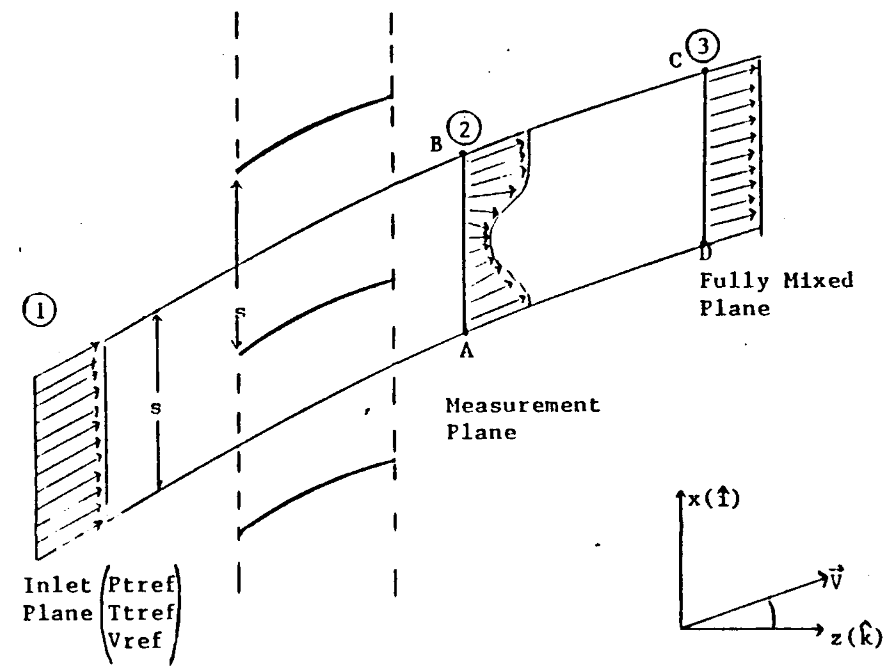


Figure D1. Fully Mixed-Out Conditions for a Stationary Cascade

D1. FULLY-MIXED-OUT SOLUTIONS

Figure D1 illustrates the concept of fully-mixed-out conditions for a stationary cascade. For loss calculations, the mixed-out conditions must first be calculated from measurements made at both station 1 and station 2. However, the procedure will only be shown here for station 2 to hypothetically mixed-out conditions at station 3. The procedure from station 1 to fully mixed-out is the same. The

present procedure [Ref. 12] was found to be consistent with the method of S. everding and Starken [Ref. 13].

Measurements were made at station 2 where the flow was non-uniform. Uniform (fully-mixed-out) conditions at station 3 were calculated from those at station 2 using conservation of mass, momentum and energy for the control volume labeled ABCD.

Assumptions are made that the flow is steady, that the gas is a perfect gas with constant specific heats and that the stagnation temperature is uniform throughout the flow.

Conservation of energy is satisfied by the assumption of constant stagnation temperature, thus

$$T_{t3} = T_{t2} = T_t \tag{1}$$

Conservation of mass yields

$$\rho_3 V_3 \cos\beta_3 = \int_0^s \rho_2 V_2 \cos\beta_2 \tag{2}$$

Conservation of momentum yields

$$0 = \int_{AB} \vec{V} d\dot{m}_2 - \int_{DC} \vec{V} d\dot{m}_3 + \int_{AB} d\vec{F}_2 + \int_{DC} d\vec{F}_3 \tag{3}$$

where $d\vec{F}$ is the component of force on an elemental area of the control volume's surface. No contribution to the conservation equation results from the periodic conditions along BC and AD.

If the integral of the shear stresses over AB is neglected, the component of Eqn. (3) in the x-direction becomes

$$\rho_3 V_3^2 \cos\beta_3 \sin\beta_3 = \int_0^1 \rho_2 V_2^2 \cos\beta_2 \sin\beta_2 d(\frac{x}{s}) \tag{4}$$

With no assumptions, the component of Eqn. (3) in the z-direction becomes

$$P_3 + \rho_3 V_3^2 \cos^2\beta_3 = \int_0^1 (\rho_2 V_2^2 \cos^2\beta_2 + P_2)\, d(\frac{x}{s}) \tag{5}$$

Equations (2), (4) and (5) give conditions at station 3 in terms of those measured at 2. Using the equation of state and constant stagnation temperature, the four unknowns (P_3, ρ_3, V_3, β_3) can be reduced to three. Introducing the limiting velocity

$$V_t = \sqrt{2 C_p T_t} \tag{6}$$

which, here, is a constant, and defining a dimensionless velocity as

$$X = \frac{V}{V_t} \tag{7}$$

the steady flow energy equations and isentropic relationships give

$$\frac{T}{T_t} = 1-X^2 \tag{8a}$$

$$\frac{P}{P_t} = (1-X^2)^{\frac{\gamma}{\gamma-1}} \tag{8b}$$

$$\frac{\rho}{\rho_t} = (1-X^2)^{\frac{1}{\gamma-1}} \tag{8c}$$

Multiplying the left hand side (LHS) of Eqn. (4) by

$$\frac{1}{\rho_{t3}V_t^2}$$

and the right hand side (RHS) by

$$\frac{1}{\rho_{t2}V_t^2}\left(\frac{\rho_{t2}V_t^2}{\rho_{t3}V_t^2}\right)$$

and using the equation of state with T_t as constant,

$$P_{t3}X_3^2(1-X_3^2)^{\frac{1}{\gamma-1}}\cos\beta_3\sin\beta_3=\int_0^1 P_{t2}X_2^2(1-X_2^2)^{\frac{1}{\gamma-1}}\cos\beta_2\sin\beta_2 d\left(\frac{x}{s}\right) \tag{9}$$

Similarly, from Eqn. (5), noting that $2Cp/R = (2\gamma/\gamma-1)$

$$P_{t3}[(1-X_3^2)^{\frac{\gamma}{\gamma-1}}+\left(\frac{2\gamma}{\gamma-1}\right)X_3^2(1-X_3^2)^{\frac{1}{\gamma-1}}\cos^2\beta_3] =$$

$$\int_0^1 P_{t2}[(1-X_2^2)^{\frac{\gamma}{\gamma-1}}+(\frac{2\gamma}{\gamma-1})X_2^2(1-X_2)^{\frac{1}{\gamma-1}}\cos^2\beta_2]\,d(\frac{x}{s}) \qquad (10)$$

and from Eqn. (2)

$$P_{t3}X_3(1-X_3^2)^{\frac{1}{\gamma-1}}\cos\beta_3=\int_0^1 P_{t2}X_2(1-X_2^2)^{\frac{1}{\gamma-1}}\cos\beta_2\,d(\frac{x}{s}) \qquad (11)$$

Equations (9), (10) and (11) are three equations for unknowns P_{t3}, X_3 and β_3.

Identifying the three RHS integrals as

$$I_1=\int_0^1 P_{t2}X_2(1-X_2^2)^{\frac{1}{\gamma-1}}\cos\beta_2\,d(\frac{x}{s}) \qquad (12a)$$

$$I_2=\int_0^1 P_{t2}X_2(1-X_2^2)^{\frac{1}{\gamma-1}}\cos\beta_2\sin\beta_2\,d(\frac{x}{s}) \qquad (12b)$$

$$I_3=\int_0^1 P_{t2}[(1-X_2^2)^{\frac{\gamma}{\gamma-1}}+(\frac{2\gamma}{\gamma-1})X_2^2(1-X_2^2)^{\frac{1}{\gamma-1}}\cos^2\beta_2]\,d(\frac{x}{s}) \qquad (12c)$$

and eliminating P_{t3} by dividing Eqn. (11) into Eqn. (9) and Eqn. (10) yields

$$X_3\sin\beta_3=\frac{I_2}{I_1}=A \qquad (13)$$

Similarly, dividing Eqn. (11) into Eqn. (10) obtains

$$\frac{[(1-X_3^2)+(\frac{2\gamma}{\gamma-1})X_3^2\cos^2\beta_3]}{X_3\cos\beta_3}=\frac{I_3}{I_1}=B \tag{14}$$

Equation (13) and Eqn. (14) are simultaneous equations for X_3 and β_3 in terms of A and B, which are known from measurements. Squaring Eqn. (14) and substituting for $\cos^2\beta_2$ using Eqn. (13),

$$B^2X_3^2-B^2A^2 - [1-(\frac{2\gamma}{\gamma-1})A^2+(\frac{\gamma+1}{\gamma-1})X_3^2]^2 \tag{15a}$$

which is also

$$(\frac{\gamma+1}{\gamma-1})^2X_3^4+\{2(\frac{\gamma+1}{\gamma-1})[1-(\frac{2\gamma}{\gamma-1})A^2]-B^2\}X_3^2+\{[1-(\frac{2\gamma}{\gamma-1})A^2]^2+B^2A^2\} - 0 \tag{15b}$$

Equation (15b) is a quadratic equation for X_3^2, yielding an explicit solution

$$X_3^2=\frac{-D\pm\sqrt{D^2-4CE}}{2C} \tag{16}$$

where

$$C=(\frac{\gamma+1}{\gamma-1})^2 \tag{17}$$

$$D=2(\frac{\gamma+1}{\gamma-1})[1-(\frac{2\gamma}{\gamma-1})A^2]-B^2 \tag{18}$$

$$E=[1-(\frac{2\gamma}{\gamma-1})A^2]^2+B^2A^2 \tag{19}$$

The alternate signs in Eqn(16) correspond to subsonic and supersonic roots. [Ref. 13] When X_3 is known from Eqn. (16), β_3 is given by Eqn. (13), P_{t3} by Eqn. (11) and P_3 by Eqn. (8b). These are the fully-mixed-out conditions.

D.2 INTRODUCTION OF REFERENCE CONDITIONS

In practice, when probe surveys are conducted to obtain the integrals in Eqn. (12), fluctuations occur in tunnel supply conditions. The integrals in Eqn. (12) are to account for spatial variations in properties. If time variations occur, the effect on the spatial integral can be minimized by referencing the integrand to tunnel reference conditions at the time of the measurement (Duval [Ref. 9]).

Ptref, Ttref and Xref are defined as the tunnel reference conditions at the time of each individual measurement, and $\hat{P}_{ref}$, $\hat{T}_{ref}$ and $\hat{X}_{ref}$ as the ensemble average values of the reference conditions over all points in the integration interval.

The conservation of mass equation is divided by the reference mass flux

$$\rho ref Vref = \left(\frac{2\gamma}{\gamma-1}\right) Xref(1-Xref^2)^{\frac{1}{\gamma-1}}\left(\frac{Ptref}{Vtref}\right) \qquad \textbf{(20)}$$

and the momentum equation by the reference momentum flux

$$\rho refVref^2=\left(\frac{2\gamma}{\gamma-1}\right)Xref^2(1-Xref^2)^{\frac{1}{\gamma-1}}Ptref \tag{21}$$

Dividing Eqn. (11) by ρrefVref with Vtref = constant,

$$\hat{I}_1=\int_0^1\frac{P_{t_2}X_2(1-X_2^2)^{\frac{1}{\gamma-1}}\cos\beta_2}{PtrefXref(1-Xref^2)^{\frac{1}{\gamma-1}}}d\left(\frac{x}{s}\right)=\frac{Pt_3X_3(1-X_3^2)^{\frac{1}{\gamma-1}}\cos\beta_3}{\hat{P}tref\hat{X}ref(1-\hat{X}ref^2)^{\frac{1}{\gamma-1}}} \tag{11a}$$

Dividing Eqn. (9) and Eqn. (10) by ρrefV^{2}ref

$$\hat{I}_2=\int_0^1\frac{P_{t_2}X_2^2(1-X_2^2)^{\frac{1}{\gamma-1}}\cos\beta_2\sin\beta_2}{PtrefXref^2(1-Xref^2)^{\frac{1}{\gamma-1}}}d\left(\frac{x}{s}\right)=\frac{Pt_3X_3^2(1-X_3^2)^{\frac{1}{\gamma-1}}\cos\beta_3\sin\beta_3}{\hat{P}tref\hat{X}ref^2(1-\hat{X}ref^2)^{\frac{1}{\gamma-1}}}$$

(9a)

$$\hat{I}_3=\int_0^1\frac{P_{t_2}\left[(1-X_2^2)^{\frac{\gamma}{\gamma-1}}+\left(\frac{2\gamma}{\gamma-1}\right)X_2^2(1-X_2^2)^{\frac{1}{\gamma-1}}\cos^2\beta_2\right]}{PtrefXref^2(1-Xref^2)^{\frac{1}{\gamma-1}}}d\left(\frac{x}{s}\right)= \tag{10a}$$

$$\frac{P_{t_3}\left[(1-X_3^2)^{\frac{\gamma}{\gamma-1}}+\left(\frac{2\gamma}{\gamma-1}\right)X_3^2(1-X_3^2)^{\frac{1}{\gamma-1}}\cos^2\beta_3\right]}{\hat{P}tref\hat{X}ref^2(1-\hat{X}ref^2)^{\frac{1}{\gamma-1}}}$$

Dividing Eqn. (9a) and Eqn. (10a) by Eqn. (11a)

$$\frac{X_3}{\hat{X}ref}\sin\beta_3=\frac{\hat{I}_2}{\hat{I}_1}$$

and

$$\frac{[(1-X_3^2)+(\frac{2\gamma}{\gamma-1})X_3^2\cos^2\beta_3]}{X_3\hat{X}ref\cos\beta_3}=\frac{\hat{I}_3}{\hat{I}_1}$$

This leads to the following equations:

$$\hat{A}=\hat{X}ref(\frac{\hat{I}_2}{\hat{I}_1})=X_3\sin\beta_3 \tag{22}$$

$$\hat{B}=\hat{X}ref(\frac{\hat{I}_3}{\hat{I}_1})=\frac{[(1-X_3^2)+(\frac{2\gamma}{\gamma-1})X_3^2\cos^2\beta_3]}{X_3\cos\beta_3} \tag{23}$$

The solution for X_3 is given by Eqn. (16) using $\hat{A}$ and $\hat{B}$ in Eqn. (18) and Eqn. (19). Then, the mixed-out-flow conditions are given by

$$\beta_3=\sin^{-1}(\frac{\hat{A}}{X_3}) \tag{24}$$

$$Pt_3=\frac{\hat{P}tref\hat{X}ref(1-\hat{X}ref^2)^{\frac{1}{\gamma-1}}\hat{I}_1}{X_3(1-X_3^2)^{\frac{1}{\gamma-1}}\cos\beta_3} \tag{25}$$

$$P_3=Pt_3(1-X_3^2)^{\frac{\gamma}{\gamma-1}} \tag{26}$$

APPENDIX E

FULLY-MIXED-OUT FLOW SOFTWARE TESTING

E1. INTRODUCTION

After coding the fully-mixed-out flow calculation within the software developed by Classick, a test of the software was required using an initial profile for which the mixed-out conditions could be determined exactly. By applying the test case, it was possible to determine that there were no fundamental errors in the programming.

Figure E1 shows the selected test case for which the analytical solution was programmed on an HP 9830A [Ref. 11] computer.

$x = 0 - 1.5$	$x = 1.5 - 3.0$
$X_B = 0.1$	$X_A = 0.05$
$\beta = 20, 0$	$\beta = 20, 0$
$P = 401''$ water	$P_{tref} = 430''$ water
$P_a = 400''$ water	$T_t = 520°R$

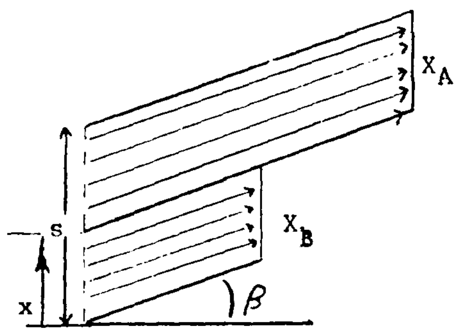


Figure E1. Fully-mixed-out Flow Test Case

The test case was provided to "LOSS" as a reduced file for inlet flow angles of zero and 20 degrees. Zero degrees was chosen to ensure that the flow angle did not change as a result of calculation errors. The value of 20 degrees was

chosen to provide a reasonable test against the predictions of the analysis program.

E2. "LOSS" TEST CASE CALCULATIONS

"LOSS" was used for the test cases of zero and 20 degrees initial angle. Figure E2 shows the output at the zero initial angle, which produced no change in the mixed-out flow angle, as was expected. Figure E3 shows the output for 20 degrees initial angle, which is shown in comparison to the analytical predictions in Table E1.

E3. INDEPENDENT PROGRAM CALCULATIONS

The analysis program used closed-form expressions for the integrals involved in calculating the values of X, Pt, Ps, and yaw for the mixed-out flow (Appendix D). Figure E4 shows an output of the test case at 20 degrees initial flow angle using the values provided in Figure E1 along with a listing of the analysis program.

The analysis program was also used to look at the effects of changing initial velocity, angle, fraction of the flow at high velocity and ratio of high to low velocity on the mixed out values of X, yaw, Pt and Ps. Some results are tabulated for cases with the flow equally divided between high and low velocity in Table E2.

```
LOSS CALCULATION RESULTS FOR STATION TWO AND MIXED FLOW RESULTS.
************************************************************
USING FILES         L-27FEBACALC                    U-20MARTEST0

X2REFAVG    P2REFAVG  PAUAVG
 1.430E-01  3.000E+01 4.000E+02

 INTEGA      INTEGC      INTEGY      INTEGDI1    INTEGDI2    INTEGDI3
 2.334E+00   2.236E+00   9.698E-01   1.752E+02   2.505E+01   2.505E+01

 NUMERATOR   INTEGB      INTEGZ      INTEGNI1    INTEGNI2    INTEGNI3
 1.516E+00   1.413E+00  -8.790E+01   9.086E+01   0.000E+00   1.256E+03

DENOMINATOR
 2.345E+00

------------------------------------------------------------
STATION TWO RESULTS
___________________
STATIC PRESSURE RISE COEFFICIENT
-3.707E+01

AVDR
 6.463E-01

LOSS COEFFICIENT
 1.500E+00

------------------------------------------------------------

THE FOLLOWING IS FOR MIXED FLOW RESULTS

------------------------------------------------------------
 I1AVG     I2AVG     I3AVG     AAVG      BAVG      CAVG      DAVG
 5.186E-01 0.000E+00 5.014E+01 0.000E+00 1.382E+01 3.600E+01-1.791E+02
EAVG
 1.000E+00

XMIXFLOW  YAWMIXFLOW PTRATIO
 7.476E-02 0.000E+00  9.554E-01


PSMIXFLOW CPTMIXFLOW
 4.028E+02 9.554E-01

K3        X*K3
 5.186E-01 4.955E-01

INTEGU    INTEGT    INTEGY
 4.150E-02 1.556E+00 1.486E+00

------------------------------------------------------------

MIX FLOW RESULTS
________________

MIX FLOW STATIC PRESSURE RISE COEFFICIENT
 4.313E-01

MIX FLOW AVDR
 6.635E-01

MIX FLOW LOSS COEFFICIENT
 9.570E-01
```

Figure E2. Test Case Loss Printout--Zero Yaw Angle

LOSS CALCULATION RESULTS FOR STATION TWO AND MIXED FLOW RESULTS.

****

USING FILES L-27FEBACALC U-20MARTEST20

1-31 1-48

X2REFAVG	P2REFAVG	TAUAVG
1.430E-01	3.000E+01	4.000E+02

INTEGA	INTEGC	INTEGY	INTEGDI1	INTEGDI2	INTEGDI3
2.334E+00	2.236E+00	9.698E-01	1.752E+02	2.505E+01	2.505E+01

NUMERATOR	INTEGB	INTEGZ	INTEGNI1	INTEGNI2	INTEGNI3
1.516E+00	1.413E+00	-8.790E+01	8.538E+01	2.435E+00	1.250E+03

DENOMINATOR
2.345E+00

STATION TWO RESULTS

STATIC PRESSURE RISE COEFFICIENT
-3.707E+01

AVDR
6.463E-01

LOSS COEFFICIENT
1.500E+00

THE FOLLOWING IS FOR MIXED FLOW RESULTS

I1AVG	I2AVG	I3AVG	AAVG	BAVG	CAVG	DAVG
4.874E-01	9.719E-02	4.989E+01	2.852E-02	1.464E+01	3.600E+01	-2.024E+02

FAVG
1.163E+00

XMIXFLOW	YAWMIXFLOW	PTRATIO
7.585E-02	2.203E+01	9.554E-01

$P_{t\,mixflow}$ = 410.822

PSMIXFLOW	CPTMIXFLOW
4.026E+02	9.554E-01

K3	X*K3
4.874E-01	4.656E-01

INTEGU	INTEGT	INTEGX
3.547E-02	1.462E+00	1.397E+00

MIX FLOW RESULTS

MIX FLOW STATIC PRESSURE RISE COEFFICIENT
4.287E-01

MIX FLOW AVDR
6.235E-01

MIX FLOW LOSS COEFFICIENT
9.563E-01

Figure E3. Test Case Loss Printout--20 Degree Yaw Angle

TABLE E1

COMPARISON OF "LOSS" AND ANALYSIS PROGRAM

Mix Flow Condition	"LOSS"	Analysis
Yaw	22.09°	22.08°
X	.07585	.07584
Total Pressure	410.822" H_2O	410.829" H_2O
Static Pressure	402.6" H_2O	402.61" H_2O

```
10 REM-----*****MOTC*****-----R.P.SHREEVE------3/4/85
20 REM-----PROGRAM TO TEST THE CALCULATION OF FULLY MIXED OUT
30 REM-----FLOW FROM A CASCADE
40 REM
50 REM-----DATA STATEMENTS
60 G1=1.4
70 P9=430
80 P0=400
90 P2=401
100 X1=0.1
110 F0=0.5
120 G0=0.5
130 B2=20
140 DEG
150 REM-----CALC. INTERMEDIATE VARIABLES
160 P6=P2/P0
170 G2=G1/(G1-1)
180 F9=(1-F0)/(1-(G0*X1)↑2)
190 X8=1-(P0/P9)↑(1/G2)
200 X9=SQRX8
210 Y9=(1-X9*X9)/(1-X1*X1)
220 Y1=X1/X9
230 REM-----CALC OF I1,I2,I3
240 I1=P6*Y1*Y9*COSB2*(F0+F9*G0*(1-X1*X1))
250 I2=P6*Y1*Y1*Y9*COSB2*SINB2*(1-F9*(1-G0*G0))
260 I3=2*G2*Y1*Y1*Y9*COSB2*COSB2*(1-F9*(1-G0*G0))
270 I3=P6*((1-X8)/X8+I3)
280 REM------CALC. COEFFS. IN SOLUTION
290 A1=X9*I2/I1
300 B1=X9*I3/I1
310 C1=((G1+1)/(G1-1))↑2
320 C0=SQRC1
330 D1=2*C0*(1-2*G2*A1*A1)-B1*B1
340 E1=(1-2*G2*A1*A1)↑2+B1*B1*A1*A1
350 X4=(-D1+SQR(D1*D1-4*C1*E1))/(2*C1)
360 X5=(-D1-SQR(D1*D1-4*C1*E1))/(2*C1)
370 REM-PRINT "POSITIVE ROOT: X3="SQRX4;"NEGATIVE ROOT: X3="SQRX5
380 REM-----SELECT SMALLER(SUBSONIC)ROOT
390 X3=SQRX5
400 Z=A1/X3
410 B3=ATN(Z/SQR(1-Z*Z))
420 P3=P0*X9*(1-X3*X3)*I1/(X3*(1-X9*X9)*COSB3)
430 P4=P3*(1-X3*X3)↑(-G2)
440 REM-----CALC. STAGN. PRESSURE IN
450 P7=P2*(1-X1*X1)↑(-G2)
460 P8=P2*(1-(G0*X1)↑2)↑(-G2)
470 REM-----PRINT SECTION
480 PRINT "INPUT DATA"
490 PRINT "----------"
500 PRINT
510 PRINT "XA="X1"OVER"F0"OF BLADE SPACE"
520 PRINT "X="X1*G0"OVER"1-F0"OF BLADE SPACE"
530 PRINT "P2="P2;"BETA 2="B2
540 PRINT "PTA="P7;"PTB="P8
550 PRINT
555 PRINT "(PREF="P0;"PTREF="P9")"
556 PRINT
560 PRINT "CALCULATED MIXED OUT FLOW"
570 PRINT "-------------------------"
580 PRINT
590 PRINT "X3="X3
600 PRINT "B3="B3
610 PRINT "P3="P3
620 PRINT "PT3="P4
630 STOP
```

Figure E4. Analysis Program Listing

TABLE E2

EFFECTS OF VARIED X, YAW AND AREA

Yaw	X_B/X_A	Yaw (Mixed)	Psratio	Ptratio	% Area X_B
60	0	73.93	1.0044	.9979	.5
0	0	0	1.0179	.9911	.5
43	0	61.93	1.0015	.9953	.5
43	.05	59.60	1.0086	.9950	.5
43	.1	57.41	1.0077	.9950	.5
43	.25	51.85	1.0054	.9958	.5
43	.35	69.05	1.0040	.9966	.5
43	.45	46.92	1.0029	.9974	.5
60	.5	62.57	1.0011	.9979	.5
43	.5	51.03	1.002	.9978	.5
43	.5	46.08	1.00242	.9978	.5
40	.5	43.06	1.0026	.9978	.5
0	.5	0	1.0046	.9977	.5
20	.5	22.08	1.0040	.9977	.5
43	.55	45.37	1.0020	.9982	.5
43	.65	44.29	1.0012	.9989	.5
43	.75	43.54	1.0006	.9994	.5
43	.85	43.19	1.0002	.9998	.5
43	.95	43.02	1.0000	.9999	.5
43	1.0	43.0	1.0	1.0	.5
0	1.0	0	1.0	1.0	.5
60	1.0	60.0	1.0	1.0	.5

E4. TESTING RESULTS

The results in Table E1 show excellent agreement between the two predictions and suggest that the programmed fully-mixed-out flow calculations are correct. It is not possible, however, to determine with the programmed test case whether the calculation will be accurate for all initial conditions.

It is noted that the inlet flow angle of 43 degrees gives the maximum turning angle, during mixing, as determined by the analysis program. The angle, in all cases of varying the flow fraction at X_B, is seen to increase as the fraction decreases, until the fraction is about 0.1 of the flow area. Decreasing the ratio of X_A to X_B results in less turning in cases where the flow area fraction is one-half.

APPENDIX F

PROBE ANGLE REFERENCING

The free-jet method as described in Appendix C of Reference 6 was used to relate the measured yaw angle to the locus of the leading edges of the cascade blades. A digital precision inclinometer with a resolution of 0.1° was used in all the following angle measurements.

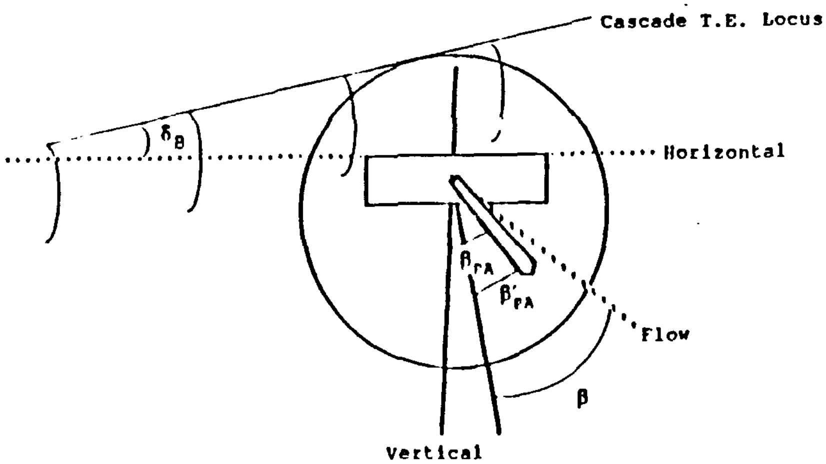


Figure F1. Probe Angle Referencing

1. Angle δ_B is the angle of the leading edge of the cascade to horizontal as illustrated in Figure F1. The average value obtained in blade-to-blade measurements was 0.25°. This compared to 0.2° as measured by Dreon [Ref. 3]. The value of 0.2° was used.

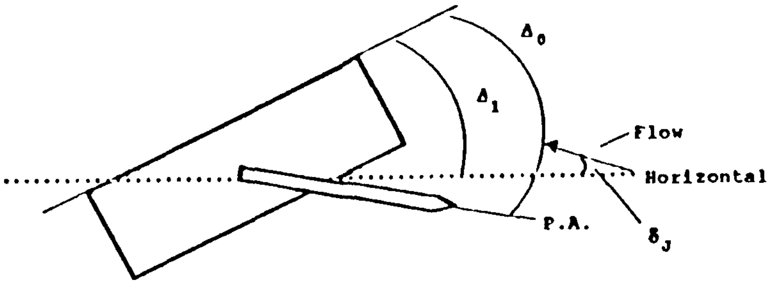


Figure F2. From North Side of Free-jet

2. Angle Δ_1--The probe was pneumatically balanced (Figure F2) at free-jet velocities of 200 and 250 feet per second yielding Δ_1 equal to 49.7° at each velocity.

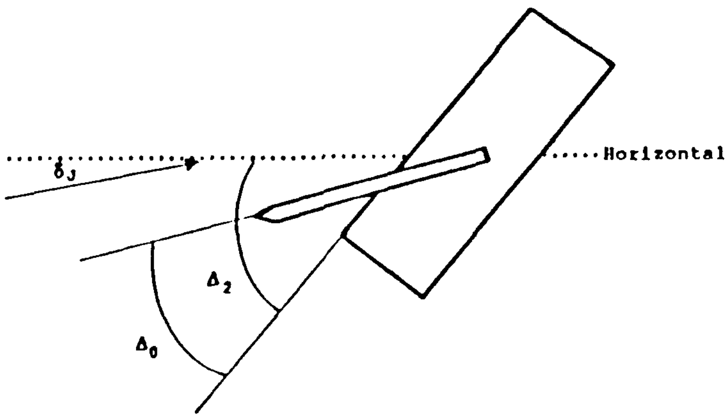


Figure F3. From South Side of Free-jet

3. Angle Δ_2--The probe was pneumatically balanced (Figure F3) at free-jet velocities of 200 and 250 feet per second yielding Δ_2 equal to 49.1° and 49.0° respectively. Δ_2 was taken to be 49.0°.

4. Angel Δ_o is the angle of the probe pneumatic axis to the surface of the bar (Figures F2 and F3).

$$\Delta_o = \left(\frac{\Delta_1+\Delta_2}{2}\right)$$

Using the measured values

$$\Delta_o = \left(\frac{49.7+49.0}{2}\right)$$

$$\Delta_o = 49.35^\circ$$

5. Angle δ_J is the inclination of the free-jet to the horizontal.

$$\delta_J = \left(\frac{\Delta_1-\Delta_2}{2}\right)$$

Using the measured values

$$\delta_J = \left(\frac{49.7-49.0}{2}\right)$$

$$\delta_J = 0.35^\circ$$

6. Angle β_{PA} is the angle of the pneumatic axis to the vertical

$$\beta_{PA} = 90-\Delta_o$$

Using the calculated value of Δ_o

$$\beta_{PA} = 90-49.35$$

$$\beta_{PA} = 40.65^\circ$$

7. Angle β'_{PA} is the angle of the pneumatic axis to the normal to the locus of the leading edges of the cascade blading.

$$\beta'_{PA} = \beta_{PA} - \delta_B = 90 - \Delta_o - \delta_B$$

Using the calculated values,

$$\beta'_{PA} = 40.45°$$

8. Angle β_H is the vernier reading when the probe bar is horizontal. Since the vernier scale is accurate only to 0.2°, β_H was measured by placing the probe's mechanical axis vertical with the inclinometer and then measuring the probe bar angle from horizontal with the inclinometer. β_H was measured to be 40.4°.

9. Angle β_F is the flow angle as measured with the probe yaw angle vernier's voltage output.

10. Angle β is the flow angle to the normal to the locus of the leading edges of the cascade blading.

Hence

$$\beta = \beta'_{PA} + (\beta_F + \beta_H)$$

yielding the final expression for the referenced yaw angle of

$$\beta = 40.45 + (\beta_F + 40.4)$$

The above expression was incorporated in the "CALC" program with a user input of β_H in the event that it should change. β_F is input from the yaw transducer during a scan.

LIST OF REFERENCES

1. NASA Technical Memorandum 82763, The Use of Optimization Techniques to Design Compressor Blading, by Nelson L. Sanger, Lewis Research Center, Cleveland, Ohio, 1982.

2. Koyuncu, Y., Report of Tests of a Compressor Configuration of CD Blading, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1984.

3. Dreon, J., Controlled Diffusion Compressor Blade Wake Measurements, Master's Thesis, Naval Postgraduate School, Monterey, California, September 1986.

4. Elazar, Y., A Mapping of the Flow Behavior in a Controlled Diffusion Compressor Using Laser Doppler Velocimetry and Preliminary Evaluation of Codes for the Prediction of Stall, Ph.D. Dissertation, Naval Postgraduate School, Monterey, California, March 1988.

5. Baydar, A., Hot-Wire Measurements of Compressor Blade Wakes in a Cascade Wind Tunnel, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1988.

6. Classick, M., Off-Design Loss Measurements in a Compressor Cascade, Master's Thesis, Naval Postgraduate School, Monterey, California, September 1989.

7. Sanger, N.L., and Shreeve, R.P., "Comparison of Calculated and Experimental Cascade Performance for Controlled-Diffusion Compressor Stator Blading," Journal of Turbomachinery, Vol. 108, No. 1, July 1986, pp. 42-50.

8. Murray, K., Automation and Extension of LDV Measurements of Off-Design Flow in a Subsonic Cascade Wind Tunnel, A.E. Thesis, Naval Postgraduate School, Monterey, California, June 1989.

9. Duval, D.A., Evaluation of a Subsonic Cascade Wind Tunnel for Compressor Blade Testing, Master's Thesis, Naval Postgraduate School, Monterey, California, September 1980.

10. User's Manual, BASIC 5.0 Graphics Techniques, Hewlett Packard, 1987.

11. Johnston, J.P. and Nishi, M., "Vortex Generator Jets--Means for Flow Separation Control," AIAA Journal, Vol. 28, No. 6, June 1990, pp. 989-1002.

12. Shreeve, R.P., Private communication, 1990.

13. Sieverding, C., and Starken, H., Aerodynamic Measurements in Cascades, AGARD-A6-207, North Atlantic Treaty Organization, April 1975, pp. 14-19.